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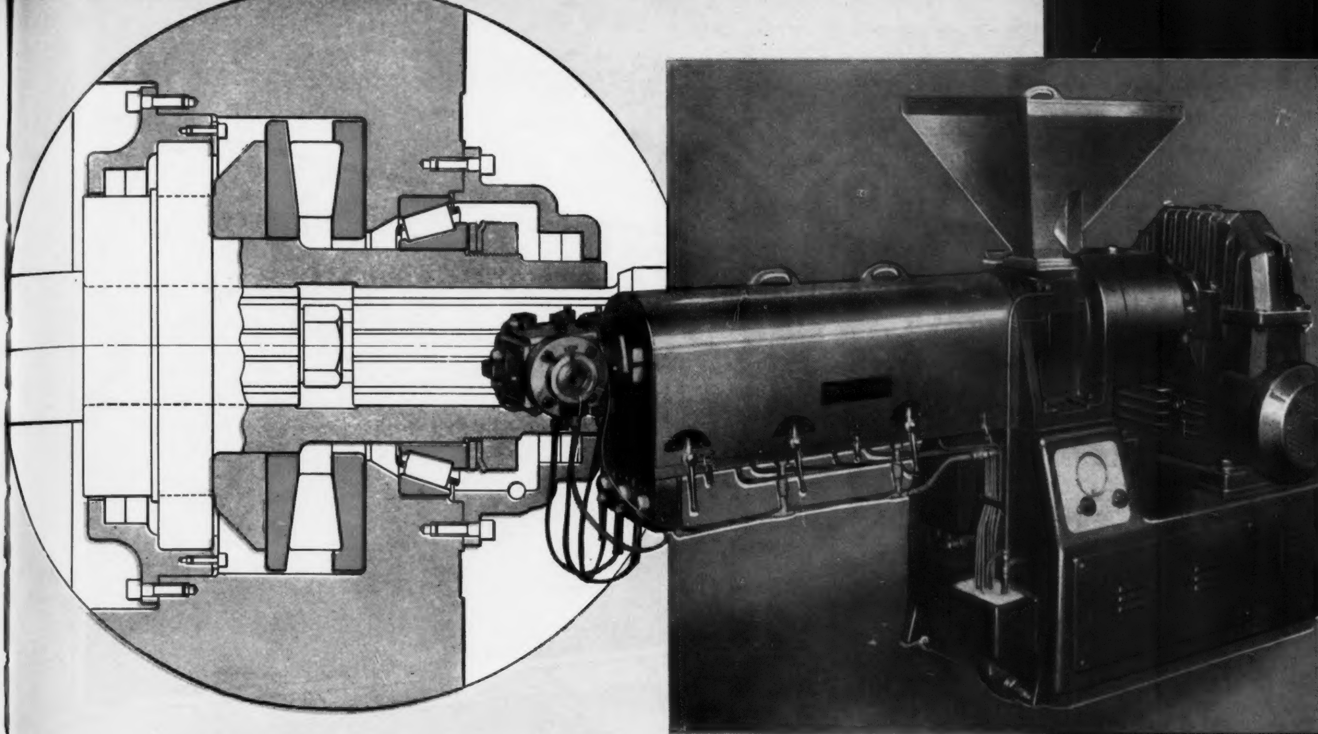

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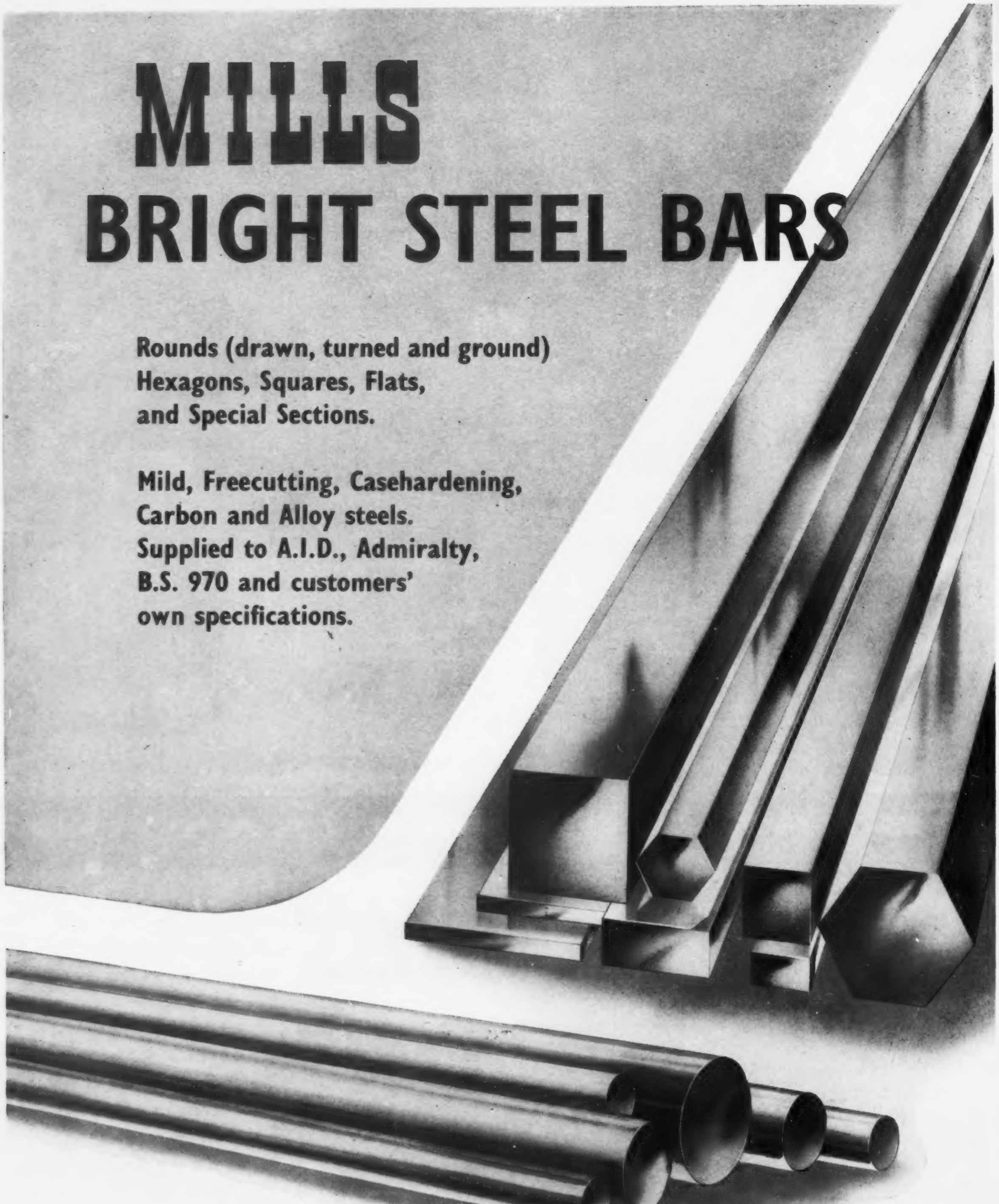

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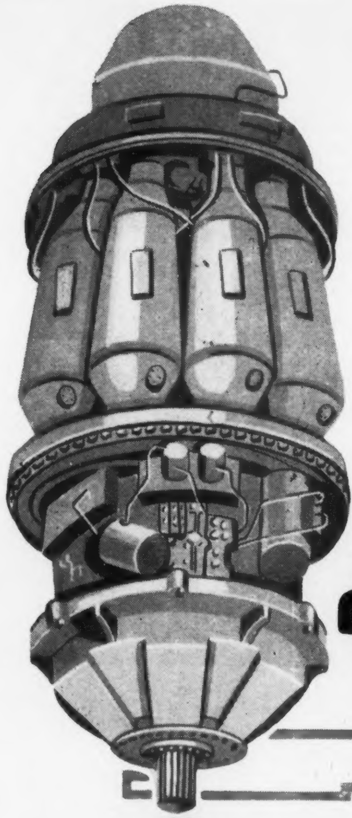

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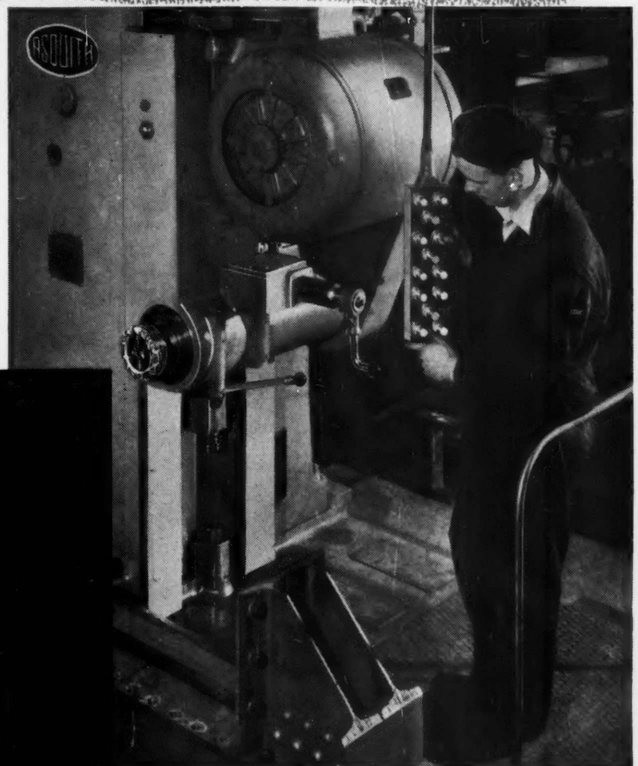

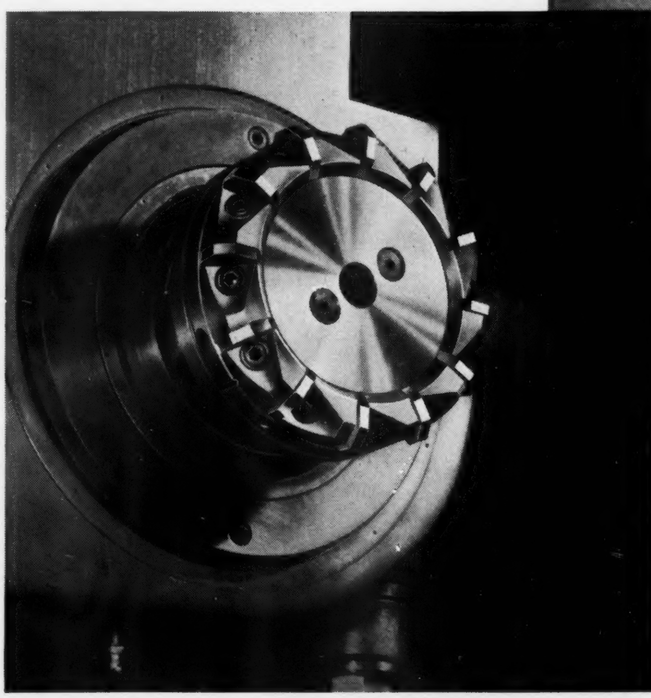

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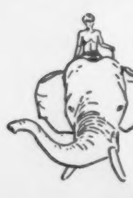

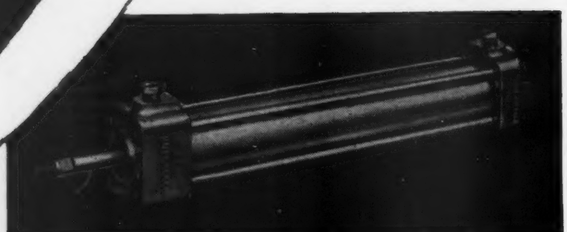

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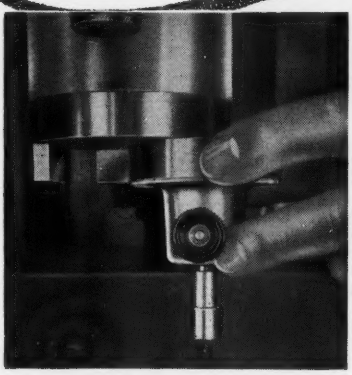

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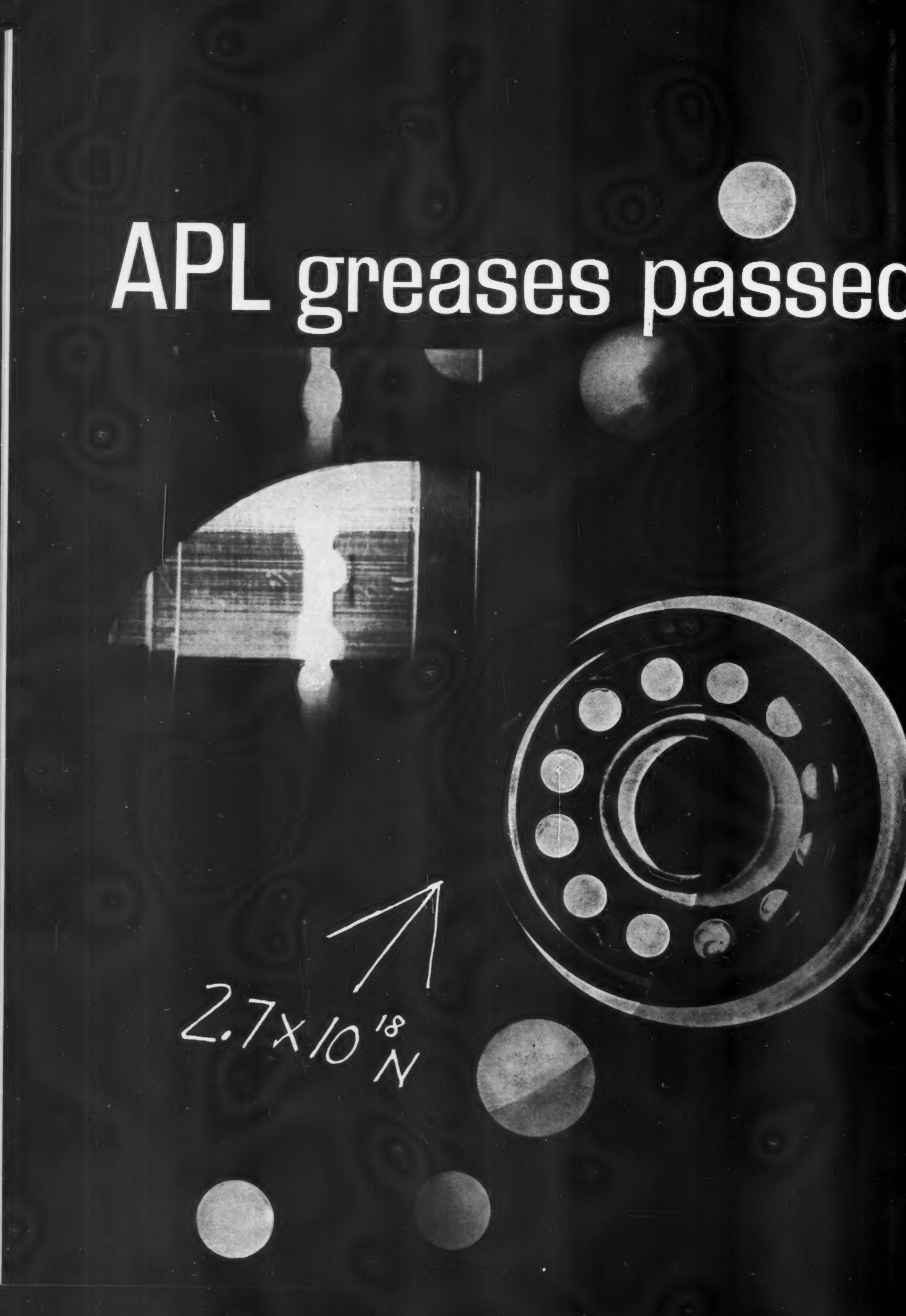

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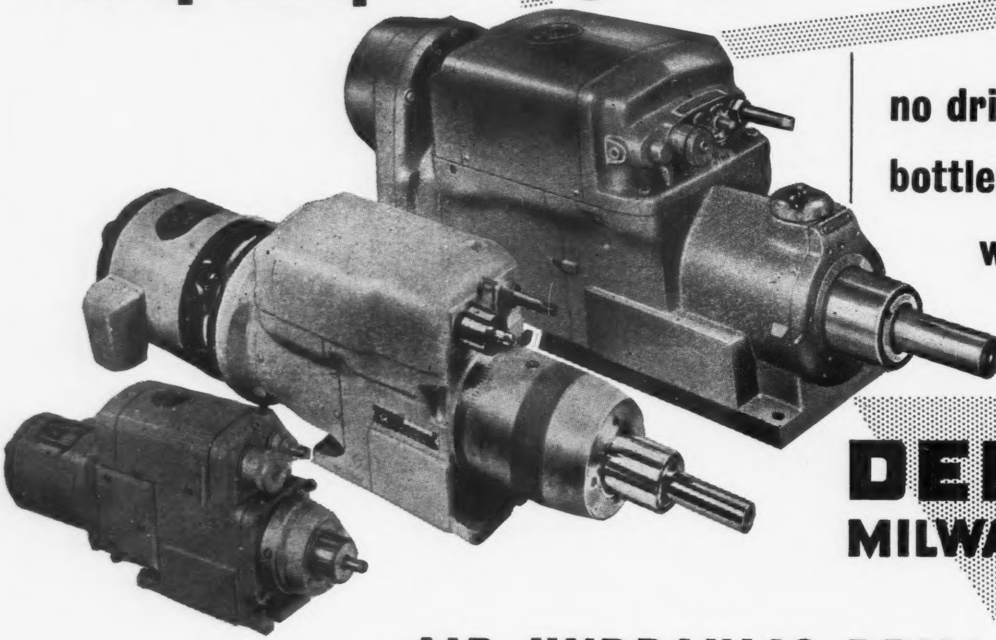

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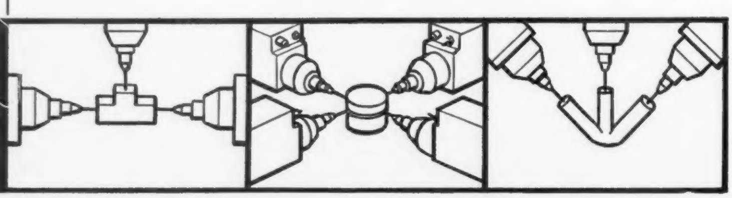

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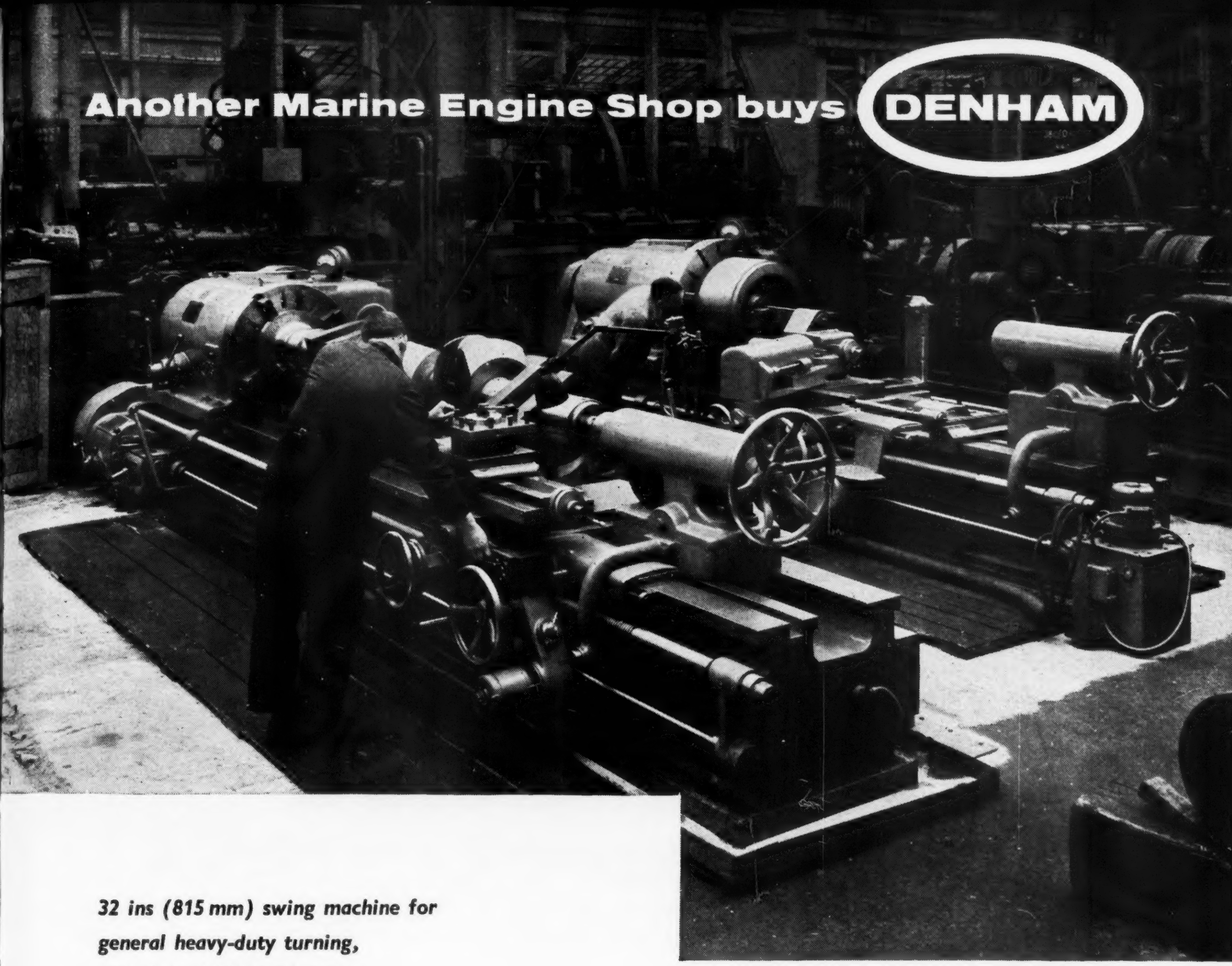

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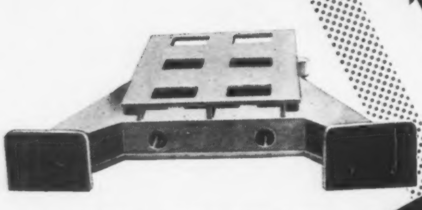
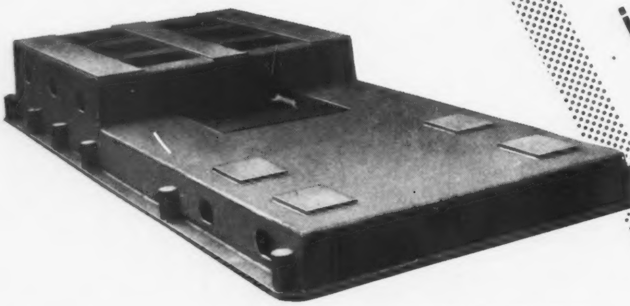


ALL WELDED MACHINE BED PLATE



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THE ANNUAL GENERAL MEETING

Thursday, 29th January, 1959

THE Annual General Meeting of the Institution was held at 10, Chesterfield Street, London, W.1, on Thursday, 29th January, 1959, at 2 p.m.

The Rt. Hon. THE EARL OF HALSBURY, F.R.I.C., F.Inst. P., President, was in the Chair.

Notice convening Meeting

THE SECRETARY (Mr. W. F. S. Woodford) read the Notice convening the meeting.

Minutes

The Minutes of the Extraordinary General Meeting held on 30th January, 1958, which had been circulated, were taken as read and were confirmed and signed as correct.

The Minutes of the Annual General Meeting held on 30th January, 1958, which had been circulated, were taken as read and were confirmed and signed as correct.

Report on Election of Members to Council

The Report on the Election of Members to Council was received on the motion of the PRESIDENT, seconded by Mr. R. H. S. TURNER.

Annual Report of Council

Mr. H. W. BOWEN, Chairman of Council, said that the Report of Council was to be found on page 42 of the January Journal, and he formally moved its adoption.

Mr. E. PERCY EDWARDS seconded the motion which was *carried*.

Statement on Income and Expenditure, Balance Sheet and Auditors' Report

Mr. H. W. BOWEN (Chairman of Council) moved the adoption of the accounts.

Mr. G. R. BLAKELY seconded, and there being no questions arising from the income and expenditure statement, balance sheet and auditors' report, the motion was put to the meeting and *carried unanimously*.

Royal Charter of Incorporation

Mr. E. F. GILBERTHORPE moved that the Institution should petition Her Majesty The Queen for a grant of a Royal Charter of Incorporation, and that the Council be empowered to take all necessary action.

Mr. J. H. WINSKILL seconded the motion which was *carried unanimously.*

Election of Auditors

On the motion of Mr. G. R. PRYOR, seconded by Mr. R. E. MILLS, Messrs. Gibson, Appleby & Co., Chartered Accountants, were re-elected Auditors to the Institution for the year 1958-1959 and were thanked for their previous services.

Election of Solicitors

On the motion of Mr. K. J. HUME, seconded by Mr. S. G. E. NASH, Messrs. Syrett & Sons were appointed Solicitors to the Institution for the year 1958-59 and were thanked for their previous services.

Council also unanimously agreed that a message of sympathy and best wishes for a speedy recovery should be conveyed to the senior partner of Messrs. Syrett & Sons, who was seriously ill.

Votes of Thanks

The PRESIDENT moved a hearty vote of thanks to all those whose work had helped to make the Institution's affairs a success in the past year. First he desired to mention all the Regional and Section Officers who were too numerous to mention by name. Then there was the Chairman of Council, Mr. Bowen, and the Vice-Chairman, Mr. Turner, both of whom had executive work to do on behalf

of the Institution which, needless to say, they had discharged throughout the year to everyone's entire satisfaction and with their usual conscientiousness.

Council would wish him to include for special mention the Chairmen of the Standing Committees who gave most generously of their time during the course of the year, and all members of the Institution who had helped in one way or another.

Lastly, of course, members of Council would wish to include in the vote of thanks the servants of the Institution, principally the Secretary, Mr. Woodford, and his staff, whose labours in the interests of the Institution had done very much to promote the welfare and prosperity of the Institution during the year just ended.

Mr. H. P. MOTT seconded the vote of thanks, which was *carried unanimously with acclamation.*

Mr. H. W. BOWEN moved a vote of thanks to the President for the excellent work which he had done. Of all the excellent Presidents which the Institution had enjoyed, none had been better than Lord Halsbury.

A vote of thanks was due to the President not only for having presided over the meetings of Council during the year, but also for the excellent work which he had done for the Institution generally.

The vote of thanks was carried by acclamation.

The PRESIDENT, in response, said it had been a pleasure to serve the Institution as President. He asked members to bear in mind that before he became President, others had laboured in the field, and when he ceased to be President, others would continue so to labour. It had fallen to his lot to be the figurehead during an important period. But there were others before and there would be others after.

The meeting then terminated.

A Report of the Meeting of Council, which took place prior to the Annual General Meeting, together with a list of Elections and Transfers, appears on pages 155 - 157.

tool wear and machinability

by E. M. TRENT, Ph.D., M.Met.

Senior Metallurgist,
Hard Metal Tools Ltd.

In this Paper, Dr. Trent sums up the work of a number of years on tool wear, and puts forward a fresh approach to the problems of metal cutting

ALTHOUGH the term machinability is used very widely and, from a practical point of view, it is readily understood what is meant when one material is declared to be more machinable than another, there is no general agreement on a definition of machinability [1]. It can be used to mean the ease of machining in terms of the power consumed under some standard conditions of cutting, or the degree of perfection of surface finish which can be obtained in machining the material, or it can be related to the tool life or rate of tool wear when the material is being cut under some standard conditions.

Each of these aspects is an important feature of what the practical man means when he refers to machinability. However, if materials are classified in terms of any one of these factors, they do not always fall in the same order as when classified in terms of the other factors. There have been many attempts to prepare an index or parameter expressing machinability in terms of a single figure based on one of the above factors, or on some other measurement such as the temperature at the cutting edge of the tool, or the cutting force measured on a tool dynamometer. Any such index is likely to be of limited value because it is too one-sided. It may be found to be very useful when applied under one set of machining conditions but to break down when applied under another, even if this involves a relatively small change such as from cutting dry to cutting with a lubricant.

Attempts to simplify and clarify the problem of machinability have always come up against this problem of the complexity of the subject. When considering all classes of machining operation, the number of variables is so great that if all of these must be considered at once and given equal weight, the result is confusion. But if the problem is simplified to one important variable, the answer is grossly one-sided.

This Paper derives from work on the wear of carbide tools. In carrying out this work, and in attempting to put the results into significant order, a method was adopted which proved to be of considerable value in summarising the accumulated information on tool wear when using a variety of tool and work materials.

Cutting speed and feed rate are variables of prime importance which must be taken into consideration in almost any cutting operation. A chart showing important features of tool wear occurring over a wide range of cutting speed and feed can be prepared for any combination of tool and work material, keeping other conditions constant. This enables a general picture, easily remembered, to be formed of the types of wear occurring. Also it enables a comparison to be made between the performance of tool materials or between the machinability of different work materials not merely under one set of conditions, but over a range, by directly comparing these charts. It has been found that, by studying tool wear in this way, much information, apparently contradictory, falls into place in a consistent pattern.

This Paper therefore has a double purpose — to present the results of work on tool wear and to submit a method of presenting these which offers a new approach to problems of machinability.

tool wear

The wear occurring on a large number of cutting tools from many different machine shop applications has been carefully observed under the microscope over a period of several years. The tools studied have been almost exclusively cemented carbide and the conclusions reached can be applied to other tool materials, such as high speed steels, only if due consideration is given to the major differences in the materials and in the way they are used. Observation of worn tools, and laboratory experiments, have shown that there are a number of qualitatively different forms of wear or deterioration of the cutting edge of the tools [2], which arise from different causes and which must, therefore, be considered separately. Frequently it is assumed that the wear on the flank or clearance face of the tool is the only form of wear which it is necessary to consider. Performance of tools is often assessed on the basis of tool life *versus* cutting speed curves in which tool life is defined as the time required to produce a wear land of some definite depth, e.g. .030 in. on the clearance face of the tool.

It is true that, in most cases where cutting conditions are good, wear on the flank of the tool is the predominant form of wear. This does not mean, however, that other factors can be ignored.

It is often found, for example, that the maximum usable cutting speed or feed is limited by the ability of the tool to withstand deformation under the cutting stresses and temperature involved, or that destruction of the cutting edge of a carbide tool has resulted from the effect of the built-up edge because the cutting speed is, perforce, too low. Wear on the flank is, therefore, not the only important form of deterioration.

In the first part of this Paper the most important forms of wear and deterioration are discussed, and methods are explained by which each can be investigated separately. These forms of deterioration are:

1. Flank or clearance face wear.
2. Cratering wear on top or rake face of the tool.
3. Build-up and associated deterioration of rake surface and cutting edge.
4. Deformation of cutting edge due to high stress and temperature.
5. Cracking at the cutting edge due to thermal stresses.
6. Chipping of the edge or fracture due to mechanical impact.

Dr. Trent studied metallurgy at the University of Sheffield where he took the degree of B.Met. in 1933. He was awarded the degree of M.Met. for work on heterogeneity in steel ingots and in 1937 was awarded a Ph.D. for research on the ageing of mild steel. From 1937 to 1942, he was employed by the Safety in Mines Research Board on investigations connected with wire ropes in mines.

Since 1942, when he took up employment with Hard Metal Tools Ltd., (an associated Wickman company) he has been engaged in research and development work on hard metals and other metal powder products. He is the author of a number of Papers on cemented carbides and on their use as cutting tools.

carbide tool materials

In this Paper only ferrous work materials (cast iron and steel) have been considered. Two main classes of carbide alloy tools were used — the class of hard metal normally used on cast iron, consisting of tungsten carbide and cobalt and the class used for cutting steel, which contains tungsten carbide, titanium carbide and cobalt. There are many varieties of these two classes of carbide tool alloy produced by different manufacturers for different applications. These vary in the proportions of cobalt and titanium carbide and some contain other carbides such as those of tantalum and niobium. They vary also in grain size. For the purposes of this Paper, and to avoid making the subject unduly complex, only the two main classes of alloy will be referred to in most cases. In the tungsten-titanium carbide tools two carbide phases are present in the structure — tungsten carbide and a solid solution of tungsten carbide in titanium carbide which is often referred to as the "mixed crystal" phase.

flank or clearance face wear

This form of wear is important in a large majority of cutting applications. It is progressive with time and the rate of wear is easily estimated by measuring under a microscope the depth of the wear land from the original cutting edge. The only difficulties encountered in measuring are that sometimes the worn surface is covered with a thin layer of the work material which obscures the cutting edge or the lower limit of the wear land, and sometimes the cutting edge has crumbled away. Steel or iron layers left on a carbide tip can easily be dissolved in acid leaving the surface practically unaffected. (This technique could not be used with high speed steel tools). If the tool edge was carefully prepared the remaining unworn part of the cutting edge can be used as a datum to measure the wear, if the worn part of the edge has crumbled.

In general, the rate of flank wear rises with increasing cutting speed but the effect of increasing feed is very variable, and it does not appear possible to give any general rule on the effect of feed rate. When speed and feed are increased to the limit where the cutting edge begins to deform, the rate of flank wear normally increases rapidly — this will be dealt with later. Under conditions where a built-up edge is present, the rate of wear when cutting steels is often erratic and, even in laboratory tool tests, reproducible results may not always be obtained. Under these conditions the presence of a cutting lubricant may have a very pronounced effect in decreasing or increasing the rate of flank wear.

The rate of wear is considerably affected by the tool geometry. In particular, increasing the clearance angle will often markedly decrease the rate of wear expressed in terms of the depth of the wear land. The depth of cut, however, has very little effect on the rate of flank wear unless it is increased to a limit where the tool deforms.

When cutting clean metal, the wear land is often lightly grooved but even and smooth and the rate of wear is fairly consistent. In a very large number of aplications, rough forged or cast surfaces are cut and this introduces variables which may be overwhelmingly large. Sand pockets at the surface of castings may cause as much wear in a few minutes as several hours of cutting in clean metal. Even in the absence of actual sand pockets, the surface skin on an iron casting or the scale on a forging can considerably increase the rate of wear on the tool.

Instead of being even, the wear land may be regular in parts but broken by deeper tongues of wear (Fig. 1). It is usually found that such points of accelerated wear are caused either by chipping of the edge or by cracks across the edge of the tool. A deep tongue of wear is sometimes formed from the point where the surface of the work piece intersects the cutting edge. There are several possible explanations for this. One is that the built-up edge flows to this point and causes excessive wear by its extreme hardness [3]. Localised wear at several times the average rate may also occur at the trailing edge (end clearance), and there may be several grooves corresponding to the feed marks on the work material. Recent investigations [4, 5], suggest that work hardening of the work surface plays a part in increasing the rate of wear at this position.

It is often stated that cutting tools ought to be re-ground when the depth of the wear land reaches some definite figure, e.g., .030 in. If regrinding is not carried out at this stage serious breakdown of the tool may occur. The reason for this appears to be associated with the formation of thermal cracks due to the stresses involved when too large an area of worn surface is being heated by friction. An example of the type of cracks formed is shown in Fig. 2. A tool in this condition is liable to fail by sudden break away of a relatively large fragment.

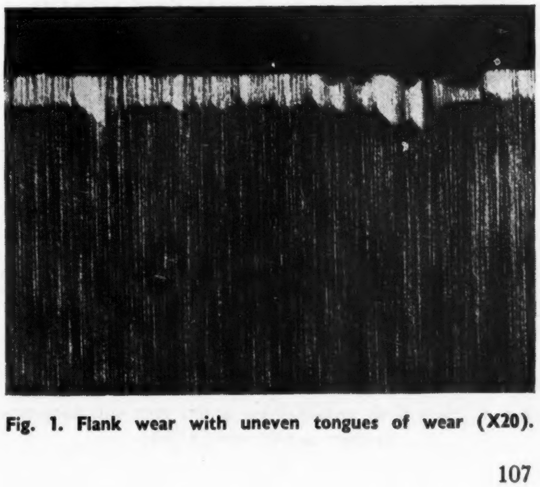

Fig. 1. Flank wear with uneven tongues of wear (X20).

Fig. 2. Excessive flank wear showing cracks (X20).

Fig. 3. Worn flank surface — smooth; tungsten-titanium carbide tool (X1500).

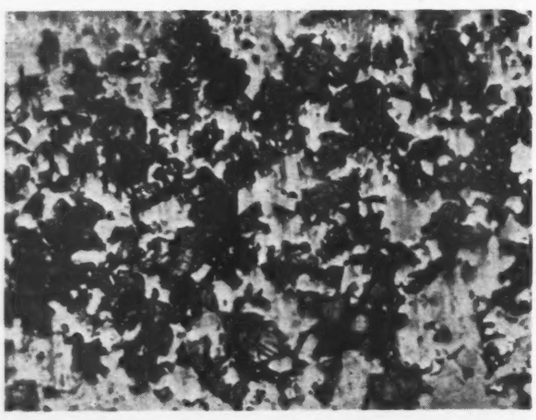

Fig. 4. Worn flank surface, many grains torn out; tungsten-titanium carbide tool (X1500).

If the worn flank surfaces are examined microscopically some crumbling of the cutting edge is often visible within a few tenths of a thousandth of an inch of the edge, but most of the worn surface is usually relatively smooth when viewed at low magnification. At high magnification either all the carbide grains can be seen to be worn through smoothly (Fig. 3) or some of the grains are smoothly worn and the remainder torn away (Fig. 4). The surface may have any degree of roughness, from the perfectly smooth to that in which only a few grains are smoothly worn. The type of surface formed depends on the carbide tool alloy, the work material and the cutting speed. While the worn surfaces are generally smoother when tungsten carbide cutting tools are used than when other carbides are present, there is no direct evidence that mixed crystal grains are torn away and tungsten carbide grains are preferentially worn through. The worn surfaces tend to become smoother as the cutting speed increases. Micro-examination has so far thrown little light on the nature of the wear processes involved on the tool flank.

cratering type wear

A typical form of wear on cutting tools is the "crater" formed on the top or rake surface of the tool at a short distance from the cutting edge (Fig. 5). It is well known that, when cutting steel with tungsten carbide tools at high speeds, cratering rapidly weakens and destroys the tool. The discovery that the addition of a small percentage of titanium carbide or other carbides could greatly reduce the rate of cratering wear was one of the major developments in carbide tool alloys.

In a previous Paper [6] a theory was put forward to account for cratering wear in steel cutting at high speeds and for the part played by titanium carbide in resisting this form of wear. The basis of this theory was that, at the very high temperatures reached at the tool-chip interface, the steel alloyed with, and probably actually fused with the tungsten carbide, the alloyed layer being carried away with the chip. Titanium carbide provided much protection because at such high temperatures it alloyed with the steel much less readily. Subsequent research has tended to confirm this theory, although it is open to question whether the local temperatures reach the fusion point.

It is quite possible for a groove very similar in appearance to be formed when machining at low cutting speeds under some conditions of cutting, but this form of wear is associated with a built-up edge and is different from high speed cratering both in its cause and in the fact that it cannot be retarded by the addition of titanium carbide to the tool alloy. Thus it is important, not only theoretically but from a practical point of view, to be able to identify the high speed form of cratering wear. This can usually be done by examining the worn surface under a microscope at high magnification after removing any adhering metal films in acid. Figs. 6 and 7 show typical worn crater surfaces (×1500)

of tungsten carbide and tungsten-titanium carbide after cutting steel at high speeds. In Fig. 6 all or nearly all the tungsten carbide grains are smoothly worn through and the surface is slightly rippled. In Fig. 7 the "mixed crystal grains" (solid solution of tungsten carbide in titanium carbide) project from the surface, the tungsten carbide grains being "dissolved" away from between them. The term "cratering", as used in this Paper, means the type of wear occurring at high speeds and identified by the surface appearance as described.

Measurement of the amount of cratering is not so simple as the measurement of flank wear, since the area and contours of the cratered surface vary greatly with different feeds, tool and work materials etc. For many test purposes, however, the important requirements are to determine whether the wear is of the cratering type or not, and to estimate from a short time test whether the rate of cratering is such that it will affect the tool life under the conditions being used. An experienced observer can usually estimate the latter by measurement of the maximum crater depth, which can be done with a microscope or by means of a surface-finish measuring instrument.

At low cutting speed and feed, cratering does not occur even when machining is carried on for a prolonged period. If the cutting speed is increased, a speed is reached at which cratering wear starts, and when this speed is reached the first signs of cratering wear can be seen on the tool after a very short period of cutting using a suitably prepared tool. As higher speeds are used, cratering wear becomes progressively more severe.

From examination of worn tools it was clear that variables other than speed and feed — for example top rake and approach angle — have quite a large effect on the rate of cratering wear while others — for example depth of cut, clearance angle and the use of cutting lubricants — have a relatively small effect. There is, however, much to be learnt as to the effect of these variables on cratering wear.

built-up edge

The built-up edge consists of work material welded to the rake surface and cutting edge of the tool under some conditions of cutting. Its occurrence has been discussed in a very large number of Papers and articles [7, 8, 9, 10, 11] since it can have a very big influence on tool life and surface finish. Like cratering, it is not an easy thing to measure, since the size and shape of the built-up edge varies greatly with the tool and work material as well as with tool geometry, cutting speed and feed, etc. The difficulty is greater than with cratering, however, since in many cases the built-up edge is removed from the tool with the chip, or broken off in handling the tool before it can be examined.

It is also necessary to investigate how far any built-up edge observed on the tool is a result of the last few seconds or fraction of a second cutting as the tool is being withdrawn, and how much it represents a condition which was present during the cutting process. In the second section of the present

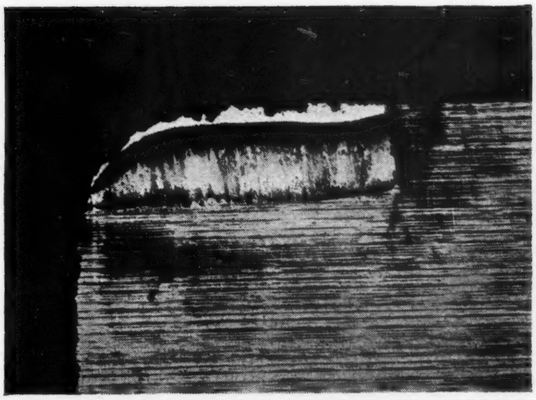

Fig. 5. Crater wear on rake surface of tungsten carbide tool (X10).

Fig. 6. Crater surface of tungsten carbide tool (X1500).

Fig. 7. Crater surface of tungsten-titanium carbide tool (X1500).

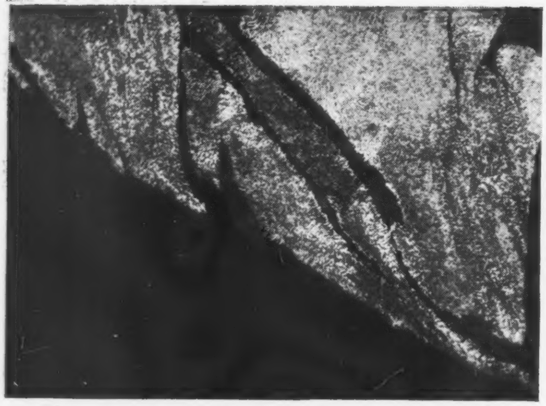

Fig. 8. Section through cast iron chip showing structure (X300).

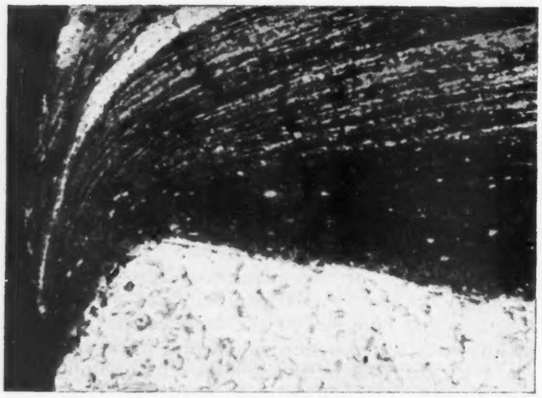

Fig. 9. Section through cast iron built-up edge on carbide tool (X1500).

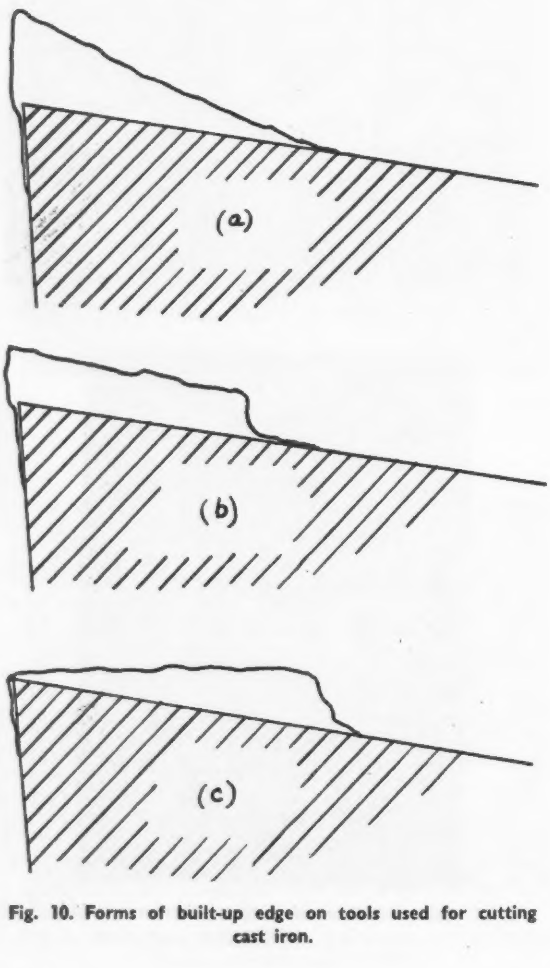

Fig. 10. Forms of built-up edge on tools used for cutting cast iron.

work, tools cutting a number of different ferrous materials under a variety of conditions were examined with special attention to the built-up edge. In a number of cases, metallographic sections through the built-up edge and tool were prepared and thoroughly examined. As a result of this work a number of conclusions have been drawn as to the part played by the built-up edge during the cutting process.

In many cases, particularly at low cutting speeds, the evidence strongly suggests that the built-up edge is present semi-permanently during the cutting process. By this is meant that metal of the shape of the built-up edge is present but that the material of which it is composed is continuously flowing. The outer layers flow rapidly and are constantly being removed and replaced. The inner layers flow more slowly and in many cases it is probable that the metal actually in contact with the tool surface does not move over this surface at all.

These conclusions are drawn from a number of observations.

1. That the built-up edge observed is something which exists during the cutting process and is not formed during withdrawal of the tool is shown by its reproducibility. Under one set of conditions one type of build-up is formed while if, for example, the speed is increased, a different type of build-up is consistently observed, and with a further increase in speed no build-up at all. There is good correlation between the size and type of the built-up edge and the roughness of the work surface and the under side of the chip.

2. The characteristics of the flow in the built-up edge are deduced from the structures observed in the metallographic sections studied. These

show clearly the lines of flow of the metal and that the metal has been plastically deformed to an extreme degree. Often in the built-up edge no trace of the original structure of the work material remains, with the exception of fragments of certain very hard constituents. This is a very much greater degree of plastic deformation than that in the bulk of the chip which is normally relatively slightly deformed — compare Figs. 8 and 9 which show the structure of a chip and of the built-up edge formed when cutting a cast iron. Only the extreme under-surface of the chip for a few tenths of a thousandth of an inch is ever distorted to the same extent. Such complete destruction of the structure could only occur by extreme distortion at relatively high temperatures.

3. That the surface of the built-up edge in contact with the tool is, in many cases, stationary is suggested by the fact that, when the build-up is removed in acid, the tool surface beneath often shows no evidence of wear even when microscopically examined at the highest magnification. In other cases a definite scoring, grooving or pulling out of fragments from the tool material shows that there has, in these cases, been relative movement of the work material over the tool surface.

Although there is much variety in the forms taken by the build-up, there are certain definite trends which are shown best in the case of cast iron. The largest built-up edge is formed at low cutting speeds, and the form is that of a fairly sharp ridge, thickest at the cutting edge as shown diagrammatically in Fig. 10a. As the cutting speed is increased the form of the build-up changes as shown in Figs. 10b and 10c and eventually it disappears entirely. While with steels, the succession of forms is not so definite, a similar trend is often observed and always a limit, dependent on speed and feed, is reached above which no definite built-up edge is observed and only very thin layers of metal are found adhering to the tool surface. Surface finish is closely related to the occurrence of the built-up edge and its shape and size.

The built-up edge may be either harmful or beneficial to the tool, depending on conditions. In the case of cast iron it is usually beneficial and it is normal to cut cast iron under conditions where a built-up edge is formed. Under these conditions the build-up largely protects the top surface from wear and reduces the rate of wear on the tool flank.

There are cases in cutting steel when the presence of a built-up edge may be beneficial, but more often it reduces tool life in one of at least three different ways. If the conditions of cutting are such that the built-up edge is apt to be broken away at the end of the cut, it frequently occurs that small fragments of the cutting edge are broken away with it. This can lead to very rapid break-down of

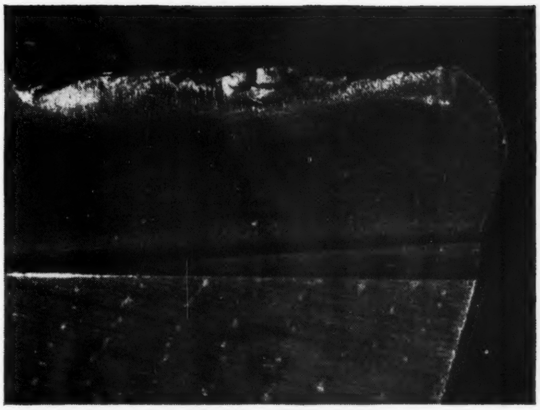

Fig. 11. Cutting edge of tool damaged by breakaway of built-up edge (X15).

the tool. An example of such a damaged cutting edge is shown in Fig. 11.

While the built-up edge may protect from wear the tool material immediately beneath it, under some conditions there may be rather severe wear in the form of a groove at its outer edge, as shown diagrammatically in Fig. 12. This type of wear is similar in appearance to high speed cratering, but it is important to distinguish between the two, since this type of wear cannot be prevented or reduced by the use of titanium in the tool alloy. Fig. 13 shows both tungsten carbide and mixed crystal grains equally worn through on such a worn surface

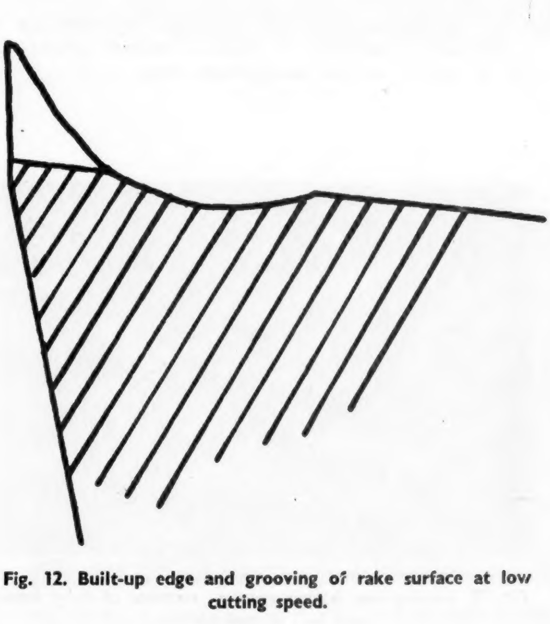

Fig. 12. Built-up edge and grooving of rake surface at low cutting speed.

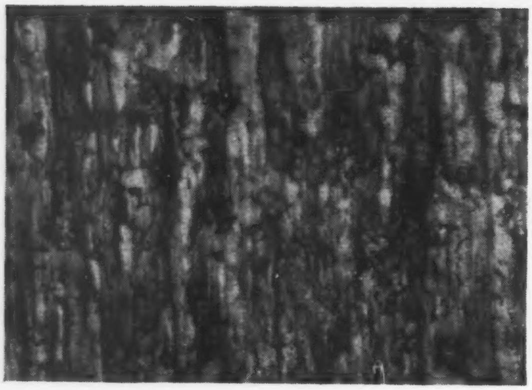

Fig. 13. Worn rake surface of tungsten-titanium carbide tool after cutting at low speed (X1500).

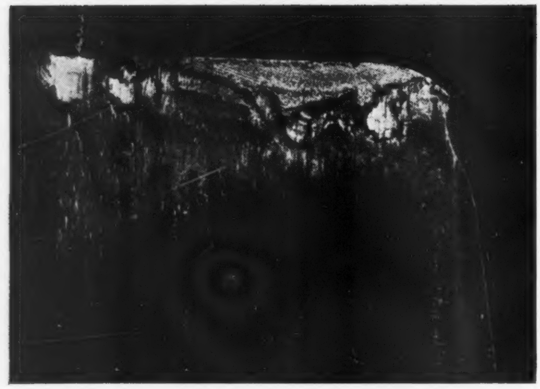

Fig. 16. Damage to rake face of tool caused during machining Nimonic alloy (X15).

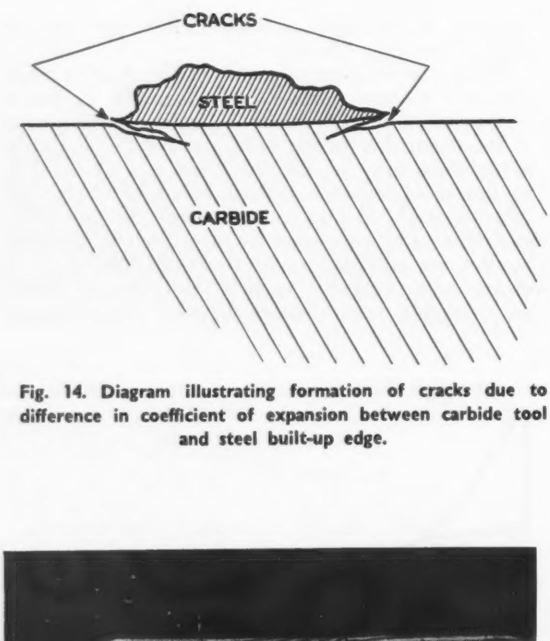

Fig. 14. Diagram illustrating formation of cracks due to difference in coefficient of expansion between carbide tool and steel built-up edge.

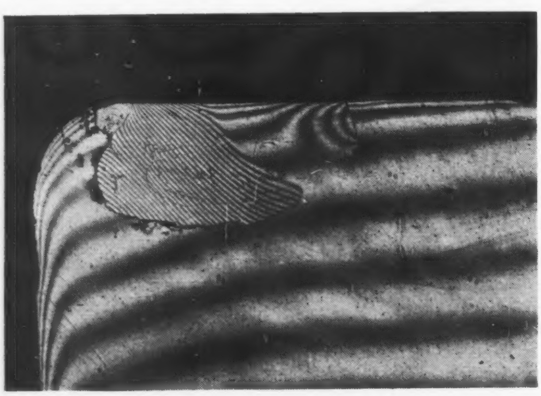

Fig. 15. Interference fringes showing removal of flake from rake face of tool (X20).

and should be contrasted with Fig. 7 which shows a surface subjected to high speed cratering. This form of wear, which can be termed grooving, can be avoided by eliminating the built-up edge, for example by increasing speed or feed.

The built-up edge can also cause severe damage in another way. The co-efficient of thermal expansion of carbide tool alloys is considerably lower than that of steel. When a large built-up edge is welded to the rake surface of the carbide tool under such conditions that the strength of the weld is high, the greater contraction of the steel during cooling, when the tool is disengaged, may cause cracks to form in the carbide from the edge of the build-up, as shown diagrammatically in Fig. 14. These cracks can be seen when the steel is dissolved in acid. Fig. 15 shows how such cracks can lead to the removal of relatively large "flakes" of carbide from the tool surface. In this case the tool had been lapped nearly optically flat before use. When the built-up edge was dissolved, the rake surface of the tool was placed on an optically flat glass plate and the interference fringes show the contours of the surface. This type of damage is more severe where the weld is strong and the co-efficient of expansion of the work material is high. These conditions are at their worst with austenitic steels and alloys of the Nimonic type. Typical damage of this sort is shown in Fig. 16.

If tests are carefully carried out and the tools examined under the microscope by an experienced observer, a short time test should be sufficient to determine whether build-up is formed under any one set of conditions, since the build-up does not appear to change greatly with cutting time.

There is much work to be done to determine how factors such as tool geometry (in particular the rake angles) and cutting lubricant influence the shape and size of the built-up edge and its effect on tool wear.

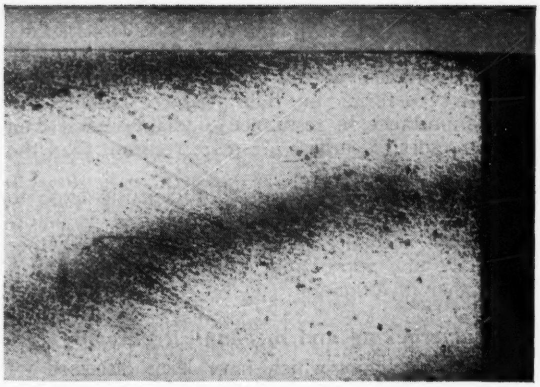

Fig. 17(a). Interference fringes on flank surface of tool before test (X40).

Fig. 17(b). Same after cutting for one minute at moderate speed (X40).

deformation

As the cutting speed is increased, the tool close to the cutting edge becomes hotter. As the feed rate is raised, both the temperature of the tool tip and the cutting force are increased. This has been shown in the published work of many workers in this field [12, 13]. With many work materials, a limit is reached above which the tool begins to deform under the influence of temperature and pressure. Such deformation has been mentioned in several publications both on high speed steel tools and carbide tools [14, 15]. One of the main advantages of carbide over high speed steel tools is the much higher resistance to deformation at higher temperature, which enables them to be used for cutting at much higher speeds. The resistance of the tool to deformation may be the property on which depends the upper limit to the cutting speeds and feeds which can be used and it is therefore of importance.

A method of investigating deformation has been developed. The clearance face of the tool tip is lapped optically flat or nearly so. After cutting for a definite time, the tip is cleaned, its clearance face is then placed on an optical glass flat and examined under monochromatic light. When tool deformation begins, the rake surface of the tool is forced down and a corresponding bulge appears on the clearance face just below the cutting edge. Such deformation is shown as a pattern of interference fringes which reveals the position and shape of the deformed zone. This is illustrated in Figs. 17(a), 17(b) and 17(c) which show the optical interference fringes on a tool as prepared and after cutting at successively higher speeds, other conditions remaining the same.

When the amount of deformation is small, the effect on tool life is negligible. Under these conditions the deformation increases only slowly with time if the cutting conditions remain constant. When deformation becomes severe, however, it leads to very rapid failure of the tool.

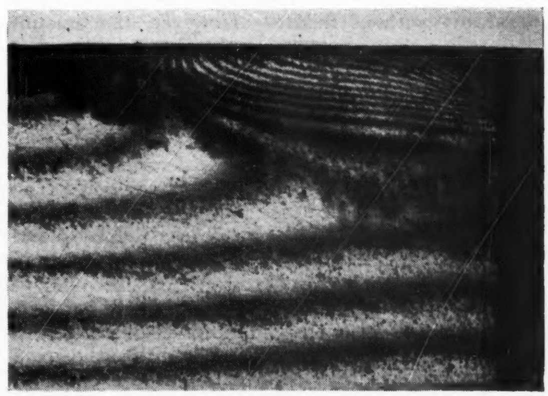

Fig. 17(c). Same after cutting for one minute at higher speed (X40).

Fig. 18. Crack on rake face of tool due to deformation (X100).

Fig. 19. Accelerated wear at nose of tool due to deformation (X10).

That deformation occurs at all on carbide tools shows that these tool materials can be deformed plastically without failure. However, the amount of plastic deformation which they can withstand is limited. The rake surface of the tool is being elongated and eventually failure may occur starting from a crack or cracks formed on this surface as shown in Fig. 18.

Under less severe conditions, deformation may lead to premature failure for another reason. The bulge on the clearance face may be of such a form that the clearance angle is greatly reduced, and flank wear thereby much increased. This leads to rapid failure, usually concentrated at the nose of the tool. Often on tools with a ground surface, deformation is not easy to observe but excessive wear at the nose of the tool, such as that shown in Fig. 19, suggests that deformation is the cause of rapid wear.

Apart from speed and feed the amount of deformation depends on depth of cut, and tool geometry among other factors. Increasing depth of cut gives increased deformation if the other conditions remain the same. As regards tool geometry, the deformation appears to be particularly related to the nose radius of the tool, since this is the position from which the heat generated at the friction surfaces is least rapidly conducted away. The smaller the nose radius, the hotter is the tool at the nose and the greater the amount of deformation. The grade of carbide tool is of importance in resistance to deformation. The harder grades of carbide are more resistant than the softer, tougher alloys.

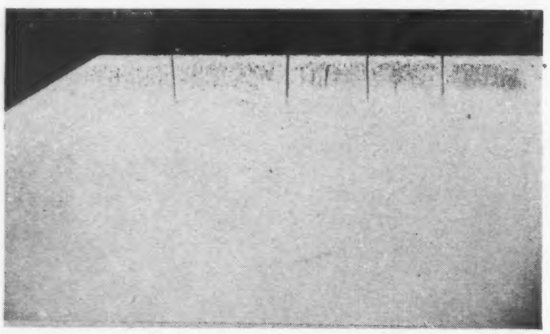

Fig. 20. Thermal cracks from the cutting edge on rake face of carbide tool (X12).

If coolants could be applied sufficiently close to the cutting edge, they might greatly reduce deformation. As normally applied it is doubtful whether they have any appreciable effect. This is a subject for further investigation.

thermal cracking and mechanical chipping

The four factors which have been discussed — flank wear, cratering, the built-up edge and deformation—are all of great importance when considering the wear of carbide tools and the machinability of ferrous materials. There are other characteristic features of worn cutting tools in particular applications and these may become so important that other forms of wear can be ignored. Two such features are thermal cracking and mechanical chipping.

Thermal cracks are so called because they appear to arise from the stresses caused by local expansion and contraction of the tool material where it is subjected to rapid changes of temperature and severe temperature gradients. Typical thermal cracks, as shown in Fig. 20, start from the cutting edge and form on planes normal to the edge. These cracks are usually quite short and often cause no loss of tool life, but they are undesirable since they may give rise to stress concentration leading to fracture of the tool.

They occur most frequently where the depth of cut is large (greater than approximately $\frac{3}{8}$ in.) or where a relatively long cutting edge is engaged. They also appear to be most severe in milling cutters where very frequent interruption of cut results in rapidly fluctuating temperatures at the tool edge. So far, however, relatively little seems to be known about this type of failure.

Mechanical chipping of the cutting edge is an all-too-frequent cause of failure. While the tool is actually cutting, the portion of the cutting edge which is embedded in the metal is unlikely to be damaged by mechanical chipping. Damage is most likely to occur when engaging or disengaging the tool, or by action of the swarf on the part of the tool edge not engaged in the cut, or by careless handling.

Where the cutting edge is chipped, subsequent cutting on this portion of the edge may lead to rapid tool failure, since the chipped portion of the edge may act as a tool with excessively large negative rake and cause severe rubbing rather than cutting. This can be dealt with in practice by eliminating the cause of chipping, by stoning the cutting edge of the tool, or by using a tougher grade of carbide. It is a factor which should be reduced to a minimum in such ways but it is not subject to any general laws relating it to speed, feed,

etc. Its general effect is to contribute to the scatter in performance figures which is such a pronounced feature of the life of cutting tools in service in the machine shop.

laboratory tool tests

The wear features described are those observed on tools used in practical applications. Observation of tools from the machine shop was supplemented by a few laboratory lathe tests and the useful information obtained suggested that a series of short time cutting tests over a wide range of speed and feed in the laboratory, followed by thorough examination of the tools, would be of value. The second half of this Paper contains the results of these tests. The methods of testing and the procedure used were as follows:

tool geometry

Top rake	...	$+8°$
Side clearance	...	$6°$
Approach angle	...	$15°$
Nose radius ...	...	$\frac{1}{32}$ in.

For the success of the method of testing used here, it is essential that the tool geometry should be maintained constant within close limits. The perfection of the cutting edge and the flatness and finish of the rake and clearance faces are important.

test procedure

Clean metal only was cut. The depth of cut was maintained constant at 0.080 in. and the cutting time was 1 minute, except for a few tests related to flank wear. No coolant or cutting lubricant was used. The cutting speed was varied from a minimum of approximately 40 ft./min. to a maximum depending on the material being cut. The feed was varied between .0029 and .0255 in. per rev. Steel or iron bars from $2\frac{1}{2}$ to 5 in. diameter by 30 in. long were turned in a Caze Neuve lathe, and normally all the tests could be carried out on one bar of each material.

examination of tools

After cutting, the built-up edge, if any, was examined and photographed when necessary. All adhering steel or iron was then dissolved in acid to reveal the clean carbide surface. The clearance face wear was photographed and measured, the rake surface was examined microscopically and the clearance face was inspected for deformation.

method of recording results

When a series of tests over the range of cutting speed and feed had been carried out, the results were plotted on a chart with the cutting speed as vertical axis and the feed per revolution as the horizontal. The regions on the chart in which the various type of wear occurred, were defined by a series of lines. For example, it was found that a line could be drawn on the chart below and to the left of which build-up occurred on the tool while above and to the right no build-up was found. Similarly with cratering and with deformation, lines could be drawn above and to the right of which these forms of deterioration were first noticed or became severe.

The lines defining the conditions under which cratering or deformation became severe are, to some extent, arbitrary. However, the error introduced on the charts by this is not great since, with both cratering and deformation, a point is reached where a further relatively small increment in cutting speed leads to very rapid breakdown, and with experience this point is not difficult to detect in a series of tests. The accuracy with which the lines can be located varies somewhat but is normally better than $\pm 10\%$ in cutting speed (e.g. between 90 and 100 ft./min. at a nominal 100 ft./min., or between 900 and 1100 ft./min. at 1000 ft./min.) and may be as good as $\pm 5\%$.

When such a chart was plotted on a scale with rectilinear co-ordinates, a series of curves was formed [16], giving a rather complicated pattern. If logarithmic co-ordinates were used, however, these curves approximated to straight lines in most cases within the limits of experimental error. This method of plotting the results of the tests appears to present the rather complex accumulation of data in its simplest form, and has been adopted for the charts presented here.

From the tool and work materials so far tested those considered in this Paper have been selected to illustrate a number of types of diagram obtained with different ferrous alloys, and to show how these diagrams can be used to present different aspects of machinability and tool wear.

results of tool tests

Charts for the following tool and work materials are given:

Fig.	*Tool Material*	*Work Material*
21	Tungsten-titanium carbide	En8-"40" carbon steel, normalised
22	Tungsten carbide	En8-"40" carbon steel, normalised
23	Tungsten-titanium carbide	En24 $1\frac{1}{2}\%$ Ni-Cr-Mo steel, normalised
24	Tungsten-titanium carbide	En24 $1\frac{1}{2}\%$ Ni-Cr-Mo steel, heat treated
25	Tungsten carbide	Meehanite GA-Pearlitic grey iron
26	Tungsten-titanium carbide	Meehanite GA-Pearlitic grey iron
27	Tungsten-titanium carbide	Martensitic stainless steel (12% Cr)
28	Tungsten-titanium carbide	Austenitic stainless steel (18% Cr, 8% Ni)
29	Tungsten-titanium carbide	Ninomic 80
30	Tungsten carbide	Free-cutting mild steel (0.24% S)
31	Tungsten-titanium carbide	Free-cutting mild steel (0.24% S)

The main features of these charts will now be considered.

"40" carbon steel — En8 — normalised

The chart for this steel when machined with a tungsten-titanium-carbide tool is given in Fig. 21. Heavy build-up occurs at speeds and feeds under the solid line. It is clear that the occurrence of the built-up edge depends on both speed and feed. At a feed of .020 in. per rev. the built-up edge disappeared when the cutting speed was greater than 70 ft./min. but at .005 in. per rev. it did not disappear until the speed exceeded 170 ft./min.

The disappearance of a large built-up edge coincided with the appearance of cratering type of wear on the rake surface of the tool. The typical cratering form of wear occurred, but the rate of this wear was low and it was not until much higher speeds were reached that cratering became so severe as to be a major factor in causing break-down of the tool. In the case of this steel, the occurrence of rapid cratering limited the maximum cutting speed which could be used, as is clearly shown on the graph. For example at .010 in. feed per rev. cratering became severe at about 900 ft. per minute.

Deformation was first detected at considerably higher speeds than cratering, and it will be noticed that the slope of the line denoting the beginning of deformation is greater than those of the other lines on the graph. This is a general feature of all the graphs and indicates that feed rate is a more important factor in deformation than in cratering. Deformation is most likely to be a serious factor at high feed rates and is unlikely to be a cause of failure at low feed rates, e.g., .001 - .005 in. per rev. In the case of this steel, deformation did not become severe under the conditions of this test, but it is quite possible that it would do so at higher feed rates or with a smaller nose radius on the tool, etc.

It is clear that it is undesirable to machine En8 with this class of tool under conditions below the solid line where heavy build-up is likely to cause fracture and erratic tool life, or above the line at which cratering becomes rapid. The most favourable range for cutting lies between these two lines, and in this range tool wear should consist largely of smooth flank wear, the rate of which will depend mainly on the cutting speed. The most economical speed for any particular cutting operation will depend on a number of specific features associated with that particular operation.

These charts are based on data in the feed range between .003 and .025 in. per rev. A certain amount of extrapolation is permissible, but this should be

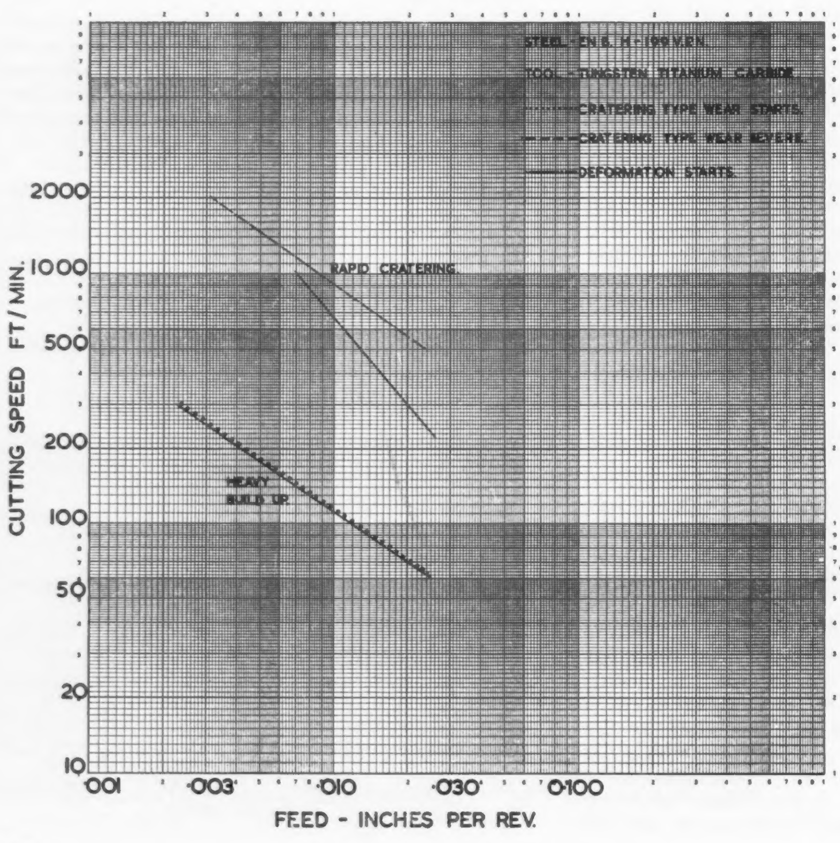

Fig. 21. Chart for En8 steel cut with tungsten-titanium carbide tools (Wimet XL3).

done with caution since other factors may intervene to prevent the lines on the graphs continuing to be straight at very low or very high feed rates. Also, the very low speeds — below 40 ft./min. — have not been explored and new wear features may occur in this region.

The chart for this steel when machined with a tungsten carbide tool is given in Fig. 22. A large built-up edge occurred up to slightly higher speeds than with the tungsten-titanium-carbide tool, though the difference was not great and the slopes of the lines were very nearly the same. When build-up occurred it was heavier and more likely to cause damage to the tool.

Cratering type of wear started at speeds rather above those at which the large build-up disappeared and above those at which it first occurred with tungsten-titanium carbide tools. For example, at .005 in. feed it was first noted at under 200 ft./min. on the tool with titanium carbide, but not until 300 ft./min. on the tungsten carbide tool. This is of more theoretical than practical interest, however, since at these speeds the small amount of cratering wear which occurred was not harmful to the tungsten-titanium carbide tool. As the cutting speed was further increased, cratering on the tungsten carbide tool became rapidly more severe and the upper limit of the useful cutting speed is defined by the line at which cratering became severe. These speeds were very much lower than those for the tungsten-titanium carbide tool — for example, 300 ft. per minute as compared with 900 ft. per minute at .010 in. feed.

The speeds at which cratering became severe were so low that deformation was not detected in any of these tests; and therefore played no part at all in tool breakdown in the range tested.

In comparison with tungsten-titanium carbide tools, the most useful cutting range for tungsten carbide, between the build-up and severe cratering lines, is very narrow. It is clear that one of the main functions of titanium carbide in the cutting tools is to raise the maximum cutting speed or feed and greatly to broaden the most useful cutting range where the tool is subject only to smooth, even flank wear.

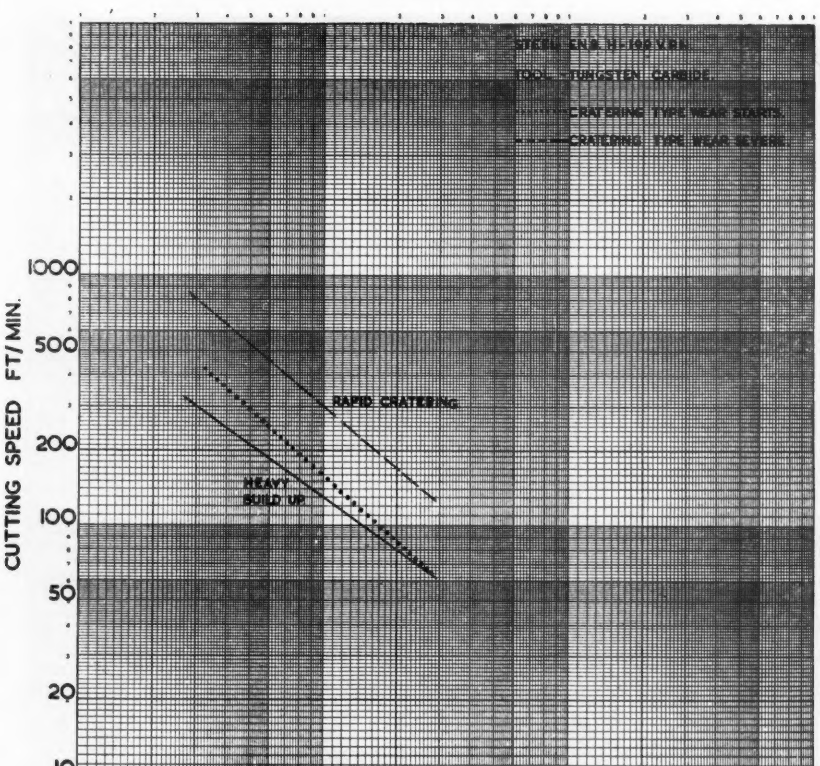

Fig. 22. Chart for En8 steel cut with tungsten carbide tools (Wimet N).

low alloy steel — En24 — normalised

The chart for this steel cut with a tungsten-titanium carbide tool is given in Fig. 23. If this is compared with Fig. 21 for En8, it is seen that heavy build-up stopped and cratering began at lower speeds with En24 than with En8, but that the difference was not great and the slopes of the lines were similar.

The main difference in the charts for the two steels was that deformation played a much more important part in the failure of tools used on En24 than on En8. With En24, it was severe deformation rather than cratering which limited the maximum cutting speed which could be used at any feed. The most useful range lies between the lower limit set by heavy build-up and the upper limit set by severe deformation. There is a wide useful range over which smooth, even flank wear predominates.

low alloy steel — En24 — heat treated to 411 V.P.N.

Fig. 24 is the chart for this steel when cut with a tungsten-titanium carbide tool. The main differences between this and the chart for the normalised steel are in the lower speeds at which heavy build-up occurs and the lower speeds at which severe deformation causes rapid collapse of the tool. For example at .010 in. feed, deformation was severe at 900 ft./min. with the normalised steel and at just over 350 ft./min. with the heat treated steel.

Although the maximum cutting speed is lowered due to the increased hardness, the minimum speed is also lowered by the reduced susceptibility to build-up, so that the most useful cutting range is still wide, although shifted to lower speeds for any given feed rate.

Severe cratering is not a problem since the tool is first destroyed by deformation. The cutting speed at which cratering wear first appears is slightly lower with the heat treated, than with the normalised steel, particularly at high feed rates, but the difference is small.

cast iron — pearlitic grey iron (Meehanite GA)

Fig. 25 gives the chart for this material, machined with a tungsten carbide tool. This can be compared with the chart for the low carbon steel machined with the same tool material — Fig. 22.

A large form of built-up edge persists on tools used on the cast iron to a higher cutting speed than with steel. At speeds somewhat higher than those at which this heavy build-up disappears the cratering

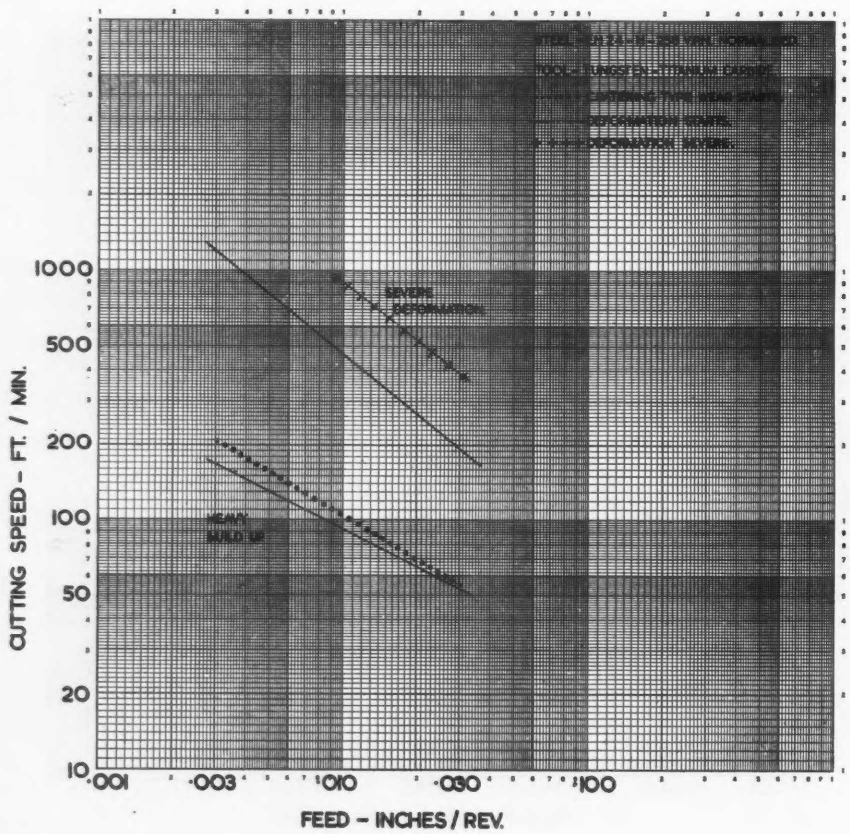

Fig. 23. Chart for En24 steel (normalised) cut with tungsten - titanium carbide tools (Wimet XL3).

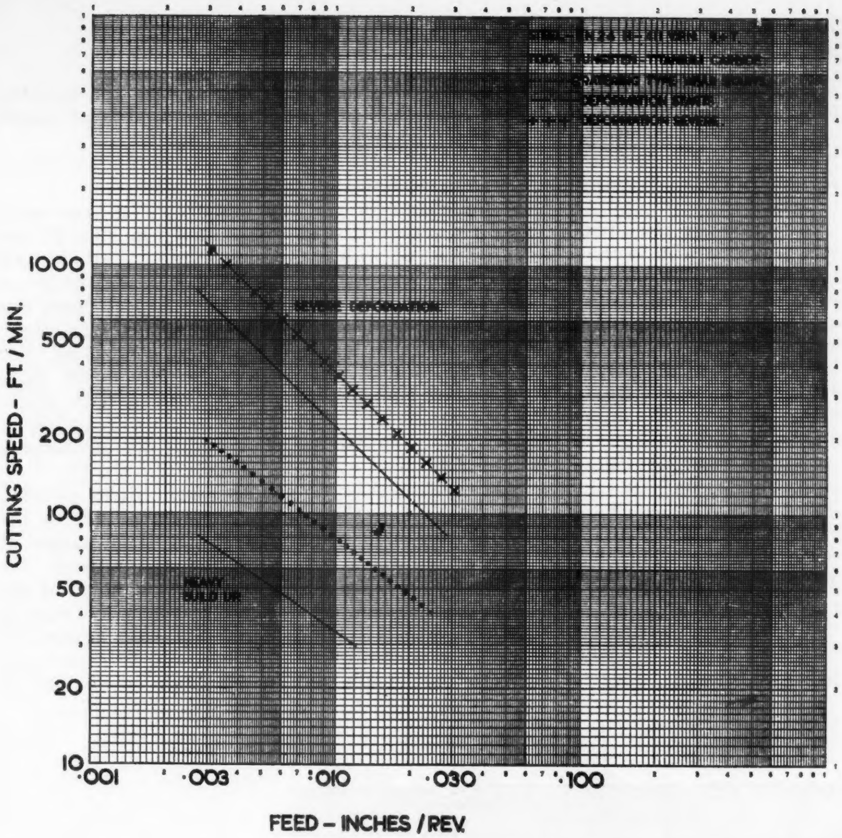

Fig. 24. Chart for En24 steel (heat treated) cut with tungsten-titanium carbide tools (Wimet XL3).

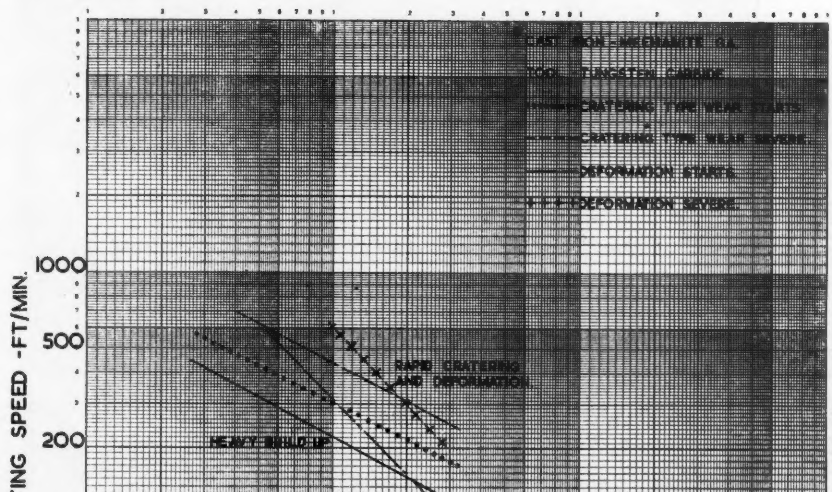

Fig. 25. Chart for pearlitic cast iron (Meehanite GA) cut with tungsten carbide tools (Wimet N).

type of wear starts, and at still higher speeds this rapidly becomes severe and can cause destruction of the tool, particularly at the lower feed rates. Deformation occurs and becomes a destructive force in a similar speed range to cratering, but is more important at higher rates of feed.

From a practical point of view, one of the main differences in machining steel and cast iron is that the built-up edge is destructive of the tool when cutting steel, but protective when cutting cast iron. For this reason machining of cast iron is most often carried out in the speed/feed range where a built-up edge occurs. The upper limit to the useful cutting range is set by severe cratering and deformation, but flank wear is also considerably more rapid when no built-up edge is present.

Fig. 26 is the chart for the same cast iron using tungsten-titanium carbide tools. Build-up occurs but ceases at about the same speed and feed as when cutting mild steel (Fig. 21) and much lower than with tungsten carbide tools on the same iron (Fig. 25). Cratering type wear starts when build-up disappears, but the titanium carbide is effective in restricting cratering so that it does not become a serious form of wear at the highest speeds tested. Deformation starts and becomes severe at nearly the same conditions as with the tungsten carbide tools. Flank wear is more rapid at all speeds on tools containing titanium carbide.

stainless steels

The charts for two stainless steels — a martensitic and an austenitic steel — are shown in Figs. 27 and 28, when cut with a tungsten-titanium carbide tool.

In the case of the martensitic steel (En56 — 12% Cr — 230 V.P.N.) the upper speed limit was set by deformation and the lower limit by build-up. The useful cutting range was rather narrow, and build-up, when it did occur, tended to be more destructive to the tool than with carbon steels. Cratering type of wear occurred, but only at higher speeds than on carbon steels, and it did not become severe.

With the austenitic stainless steel (En58 — 18% Cr, 8% Ni — 170 V.P.N.) the upper limit to the useful range of speed was set by deformation at high feed rates and by cratering at low feeds. A heavy form of build-up, visible after removal of the tool from the cut, occurred only at very low cutting speeds, but at higher speeds the chip tended to adhere very strongly to the tool and to cause very severe destruction due to its high co-efficient of

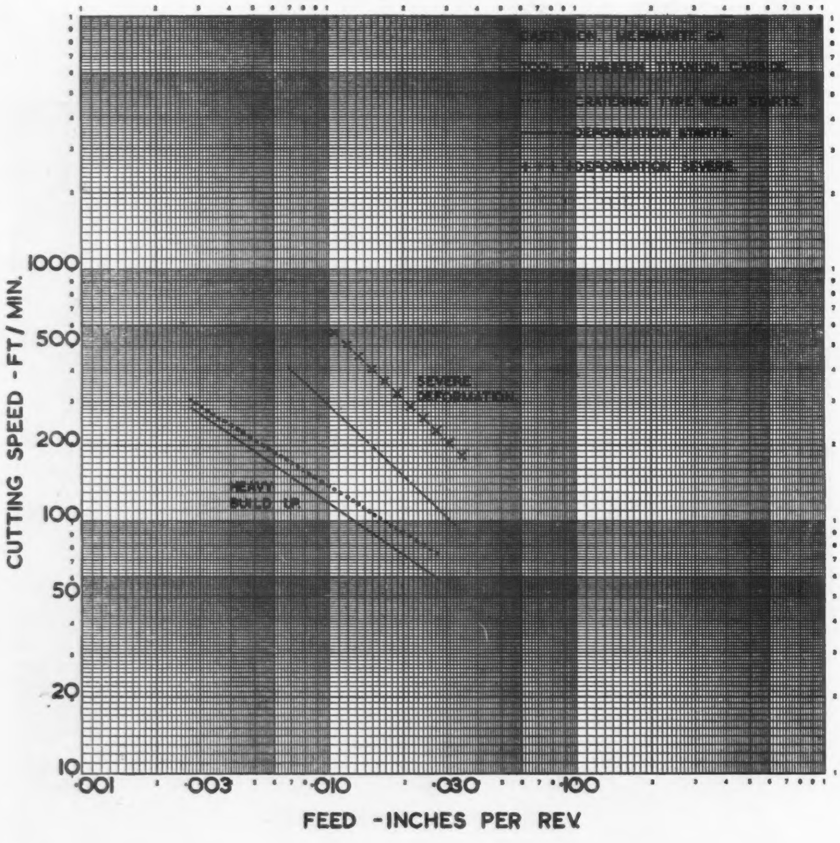

Fig. 26. Chart for pearlitic cast iron (Meehanite GA) cut with tungsten-titanium carbide tools (Wimet XL3).

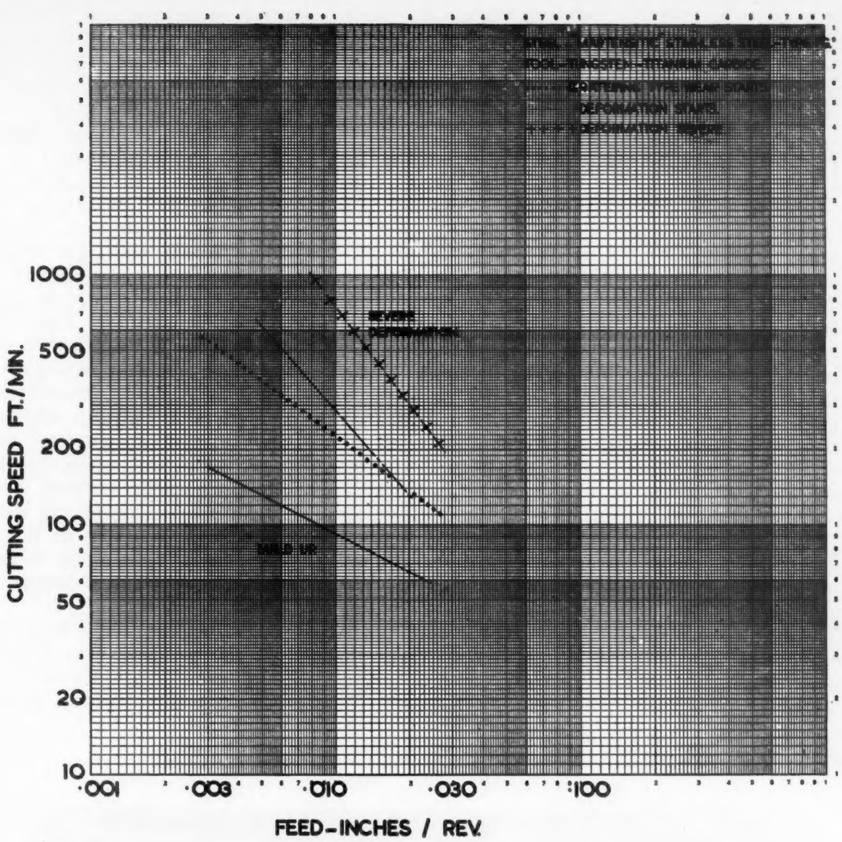

Fig. 27. Chart for martensitic stainless steel cut with tungsten - titanium carbide tools (Wimet XL3).

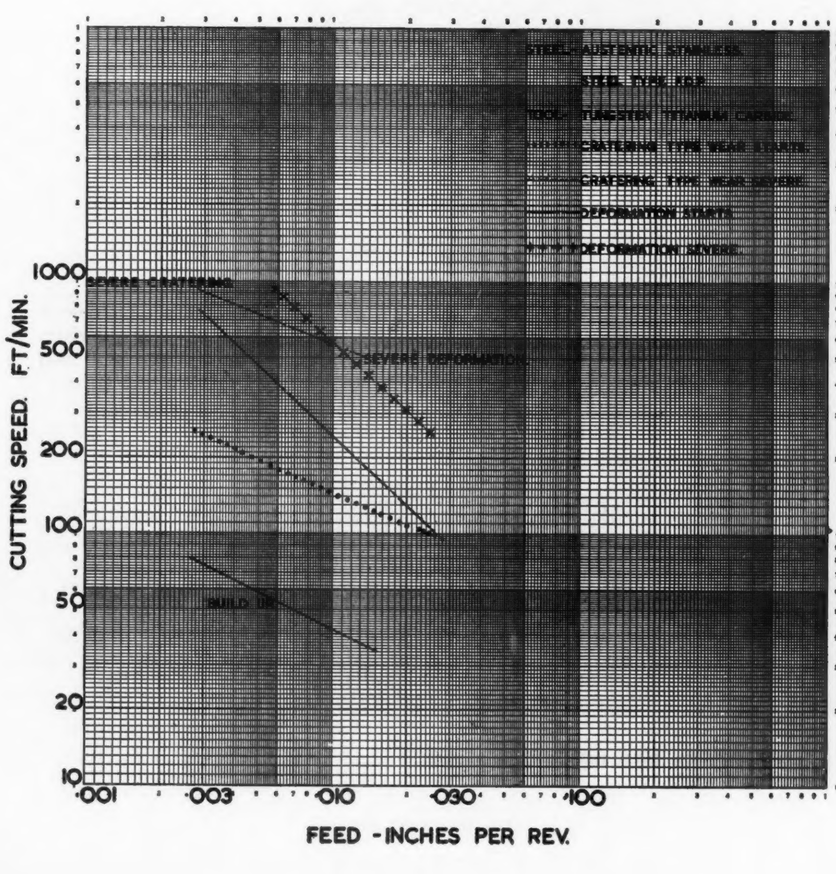

Fig. 28. Chart for austenitic stainless steel cut with tungsten-titanium carbide tool (Wimet XL3).

expansion as discussed in the section on the built-up edge.

For this reason tool life on austenitic stainless steel may be erratic at any speed, but the most useful cutting range appears to be a rather narrow one near to, and just above, the speeds at which cratering begins.

Nimonic 80

A chart for Nimonic 80 cut with a tool containing a small percentage of titanium carbide (Fig. 29) when compared with those for the other work materials shows immediately two reasons why this alloy is difficult to machine. The maximum possible cutting speed, limited by severe deformation of the tool, is much lower than for normal ferrous materials, even those of much higher hardness at room temperature. Deformation of the tool started at cutting speeds only just above those at which build-up disappeared, under the conditions of these tests, so that the useful cutting range was very narrow. These difficulties are enhanced by the very destructive nature of the build-up, associated with the fact that the chip welds very strongly to the carbide tools and has a high co-efficient of expansion. The rate of flank wear is also high.

free cutting mild steel

In contrast to the Nimonic alloys, free cutting (sulphurised) mild steel is characterised by a very wide cutting range. Figs. 30 and 31 are charts for a mild steel containing 0.24%S when cut with tungsten carbide tools and titanium-tungsten carbide tools respectively. To illustrate the profound effect of sulphur, these should be compared with the corresponding charts for a carbon steel of normal sulphur content — Figs. 22 and 21.

The tungsten carbide tools gave a chart (Fig. 30) showing some entirely new features. At the lowest part of the speed/feed range was an area in which no metallic built-up edge occurred. In this region the sulphides in the steel appeared really to function as a lubricant between carbide and steel. The chip and workpiece surfaces were left very smooth and the rake surface of the tool was lightly worn with dark films on parts of the worn area. This area of the chart is bounded by a line which is approximately straight and similar in slope to the build-up-line.

Above this line a large built-up edge was formed on the tool and existed over a wide range of speed and feed accompanied by rough chip and work surfaces. In this range there was practically no wear

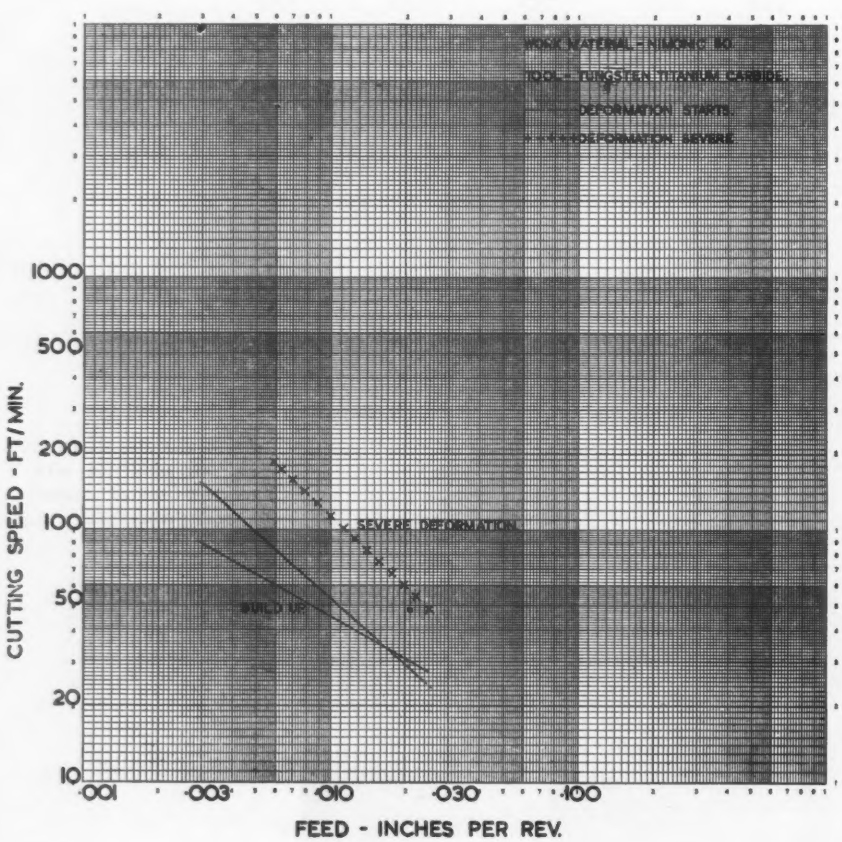

Fig. 29. Chart for Nimonic 80 cut with tungsten-titanium carbide tools (Wimet SU).

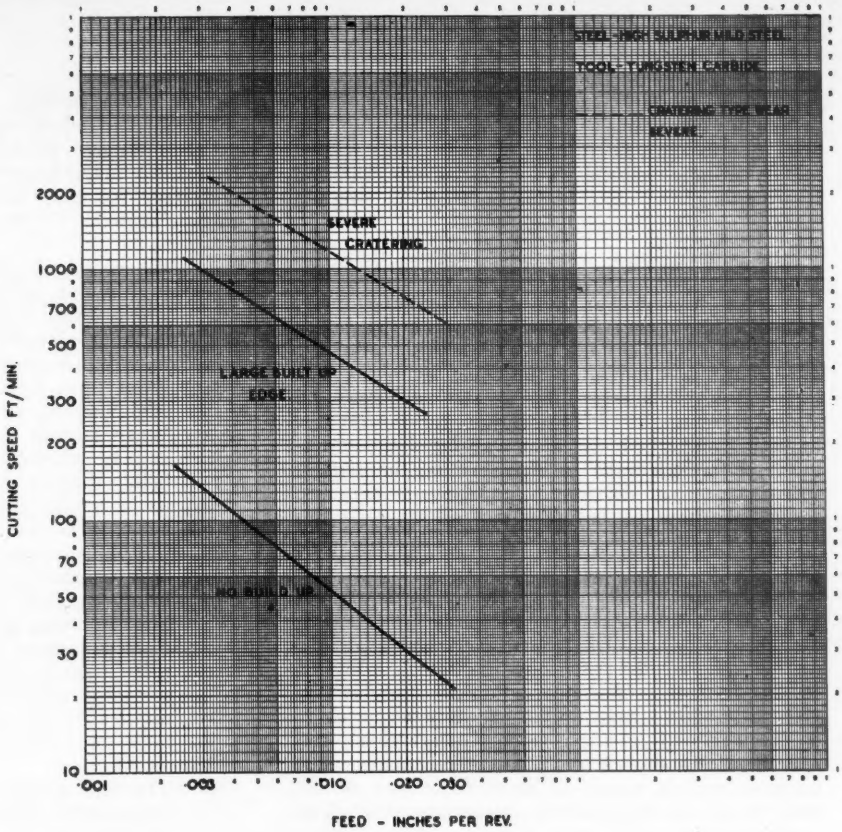

Fig. 30. Chart for high sulphur free cutting steel cut with tungsten carbide tools (Wimet N).

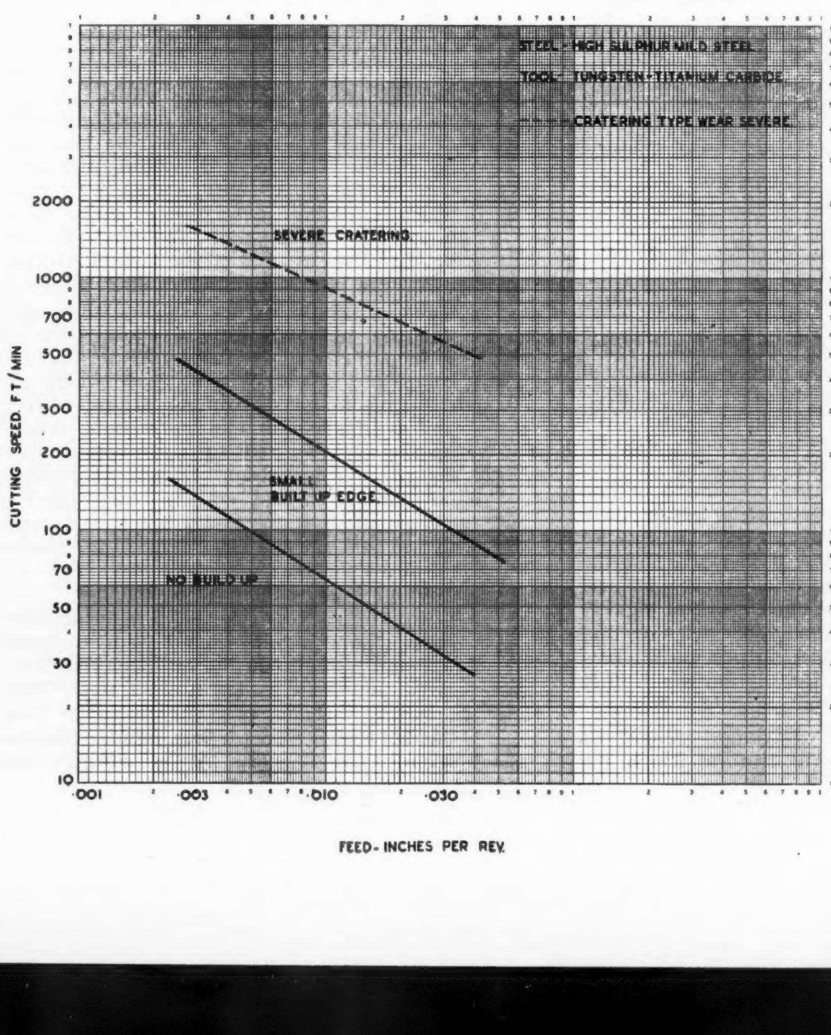

Fig. 31. Chart for high sulphur free cutting steel cut with tungsten-titanium carbide tools (Wimet XL3).

on the rake surface beneath the built-up edge, but at the upper limit of this region, as the built-up edge disappeared, a cratering type of wear started and eventually became severe, the severe cratering line defining the upper useful limit of the tungsten carbide tools on this material.

This upper limit was much higher than for tungsten carbide tools on any other steel tested, and was even higher than for the tungsten-titanium carbide tools on the free cutting steel (Fig. 31). With tungsten-titanium carbide tools the chart was of the same form and exhibited the same regions. The built-up edge, however, never became large and existed only in a much narrower region. At the lowest cutting speeds the wear was not of the cratering type on the rake surface, but at the highest speeds cratering did occur and severe cratering formed the limit of the useful cutting range. It was not possible to define a limit where cratering wear began.

The useful cutting range with the tungsten-titanium carbide tools on this type of steel is extremely wide, covering the whole speed/feed area up to the severe cratering line. With tungsten carbide tools there are two regions of usefulness at high and at low speeds with a region between where the built-up edge results in poor surface finish and may give erratic tool life. Flank wear rate on the tungsten carbide tools was lower than that on the tools with titanium carbide, particularly at high cutting speeds.

The effect of sulphur additions on stainless steel, particularly the austenitic steel, is also remarkable in the way it reduces the destructive effect of the built-up edge and broadens the useful cutting range.

general observations from machining charts

The tool-work material combinations just described illustrate the usefulness of this type of chart in relation to problems of machinability. ***An important aspect of machinability, the range of speed and feed over which normal flank or clearance face wear is the predominant form of wear and which could be called " the most useful cutting range ", is particularly clearly shown on these charts.*** These can supplement existing information on rates of flank wear. For example, the increased machinability of high sulphur steels is not completely expressed by figures showing the tool life under some particular conditions compared with steel of normal sulphur content. The extension of "the most useful cutting range" to higher and lower speeds makes these materials more adaptable to a whole variety of cutting applications. To have a knowledge of the wear characteristics over the whole range of speed and feed is useful from a practical point of view in selecting cutting conditions and tool materials, and from a theoretical point of view in providing a new method of investigating the metallurgical and other factors involved in machinability.

By surveying the whole speed/feed range the charts bring out a number of features which the ferrous materials have in common in relation to their machinability, as well as the differences between them. The following general observations have been made from examination of these charts and those for other work materials and cemented carbide tools:

1. Where a built-up edge is formed, this occurs in a region of low cutting speed and feed whose upper limit is defined by a line which is approximately straight on the double logarithmic graph. Down to 40 ft./min. no lower limit to the existence of the built-up edge was found except in high sulphur steels. When cutting cast iron, the best results are usually achieved by cutting under conditions below the line, but with steel tool life is apt to be erratic under conditions where heavy build-up occurs. With tungsten carbide tools the built-up edge is usually larger than with tools containing titanium carbide; it is more firmly welded to the carbide, persists to higher cutting speeds, affords more protection to tools turning cast iron, and is likely to do more damage to tools turning steel. Since surface finish is considerably affected by the occurrence of a built-up edge, the charts have some relevance to this question also.

2. The high speed cratering type wear normally occurs only above a definite line which lies close to the line at which build-up ceases. This usually also approximates to a straight line with a slope similar to the build-up line on the double logarithmic graphs. Above this line the rate of cratering wear increases, slowly in the case of tungsten-titanium carbide tools and rapidly with tools containing no titanium carbide. If deformation does not intervene, a limit is reached above which cratering is so severe as to cause breakdown of the tool. This also depends on both speed and feed and is defined by a line nearly parallel to that at which cratering begins. When cutting steel with tungsten - titanium carbide tools, there is a large field above the build-up line and below the severe cratering line where the most favourable conditions lie for cutting, and in this region tool life should depend mainly on the rate of flank wear unless deformation intervenes. In tools containing no titanium carbide, cratering wear starts at higher speeds, but rapidly becomes destructive so that favourable conditions for cutting lie in a very narrow field.

3. When cutting cast iron, also, cratering starts above the build-up line. With tungsten-titanium carbide this is at much the same speed and feed as for a mild steel. With tungsten carbide, cratering starts at considerably higher speeds but rapidly becomes severe once it starts. As in cutting steel,

titanium carbide is effective in reducing cratering wear to a factor of minor importance. Since cast iron is usually most efficiently cut under conditions where build-up is present, the prevention of cratering by titanium carbide is seldom required, and tungsten carbide tools give the best results.

4. The lines on the charts which define the onset of deformation and the conditions under which it becomes severe, also approximate to straight lines with a steeper slope than those for build-up and cratering. This means that deformation is relatively more important at high rates of feed. With mild steel, deformation was scarcely detected at the highest speeds and feeds used. Unlike cratering, which seemed little affected by hardness of the steel, deformation becomes much more important as the hardness (or tensile strength) of the work material increases and at higher hardness levels (e.g. over 300 V.P.N.) sets the upper limit to the speed and feed which can be used. That Nimonic alloys cause severe deformation of the tool at low cutting speeds suggests that the strength of the work material at higher temperatures also influences deformation.

5. The equations for the lines limiting the occurrence of the built-up edge, cratering and deformation in relation to cutting speed and feed are of the type

$$VF^n = K$$

where V = cutting speed
F = feed rate
n and K are constants.

This empirical relationship holds approximately for each of these phenomena on almost all the ferrous work materials and carbide tool alloys tested. The significance of this relationship should become apparent when more is known concerning the physical conditions existing near the cutting edge.

influence of other variables on machining charts

Variables other than cutting speed and feed play an important part, but many of these can be considered in terms of the alterations they would make to a machining chart made under a standard set of conditions. The above charts were prepared on the basis of tests at a depth of cut of 0.080 in., a nose radius on the tool of $\frac{1}{32}$ in., a top rake of 8°, etc.

If other test conditions had been used, the charts would not have been identical to the ones presented here. They would, in most cases, have had corresponding areas and lines of demarcation, but the lines would have been displaced from the positions shown here. The effect of other variables can be conveniently described in terms of the displacement of the lines. Little has been done so far to explore this aspect, but some variables will be discussed qualitatively.

Depth of cut. Increasing depth of cut has little effect on the build-up or cratering lines, but a larger effect on deformation. The deformation lines are lowered and deformation becomes more serious as the depth of cut is increased.

Nose radius. As with depth of cut, the effect on build-up or cratering of variations in the nose radius is small, but the effect on deformation is to lower the lines as the nose radius decreases. With very small nose radius deformation occurs at much lower speeds and feeds than shown on the charts.

Approach angle. To increase the approach angle is to reduce the undeformed chip thickness and is roughly equivalent to reducing the feed rate while maintaining a constant approach angle. It could be expected to have the effect of pushing the lines on the chart to the right by an equivalent amount.

Top rake. This is known to affect the lines for the built-up edge and cratering. A systematic investigation into the influence of top rake with different work and tool materials would be very valuable.

Side clearance. This is unlikely to affect the lines for build-up or cratering but increased clearance, by weakening the tip, is likely to lower the deformation lines to some extent.

Other variables, less easy to define, are likely also to have a considerable effect. For example, all the above tests have been carried out in clean metal. When cutting through scale, or the surface layers of a casting or forging, the tool is cutting material very different in character from clean metal and no general relationship has been established between tool wear in the skin and in clean metal, except that tool life is generally shorter and more erratic in the skin.

It has also been found that quite large variations in the rate of cratering wear can occur, even when cutting clean metal, between two bars of steel nominally of the same specification. In many cases the cause of such differences in wear rate have not yet been determined. It should be mentioned that the charts given here are based on the tool wear on one bar of each steel.

flank wear

No attempt has been made to introduce on the charts any indication of the rate of flank wear. This is for two reasons. Firstly, flank wear occurs under almost all conditions of cutting and does not follow the same laws as cratering, build-up and deformation. There are often no critical changes in the rate or type of flank wear with varying cutting speed and feed, except those associated, for example, with deformation, which are already delineated. Secondly, the charts are based on very short time cutting tests and these do not give a sufficiently accurate measure of the rate of flank wear over longer cutting times to be of value in this connection.

In these tests, however, the depth of wear on the flank of the tools after one minute cutting time was measured and some of the results are given here, as they illustrate some interesting features. Some of these have been checked in longer time cutting tests.

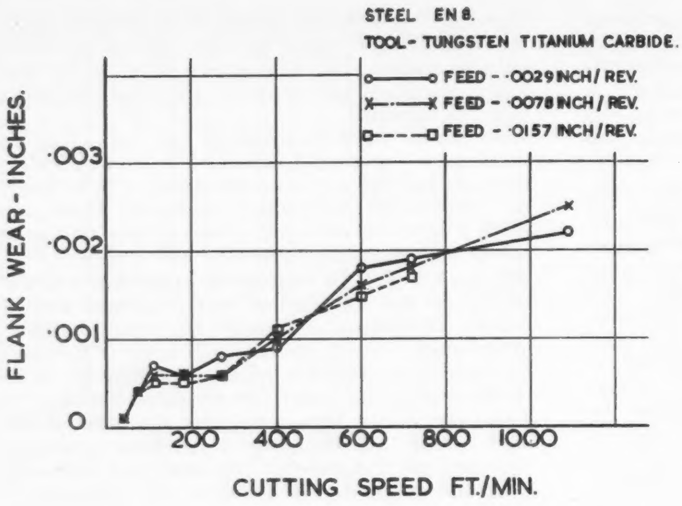

Fig. 32. Effect of speed and feed on the flank wear after one minute cutting time; tungsten-titanium carbide tools.

The experimental results confirmed in a general way the previously published work showing that the rate of wear rises steadily with increasing cutting speed but that variations in feed rate have a much smaller effect. The results, for example, of tests on a mild steel (En8) are given in Fig. 32. This shows the depth of wear on the flank of the tool after one minute cutting over a range of cutting speed and at three different feed rates.

Considering plain carbon and low alloy steels, small additions of alloying elements or relatively large variations in hardness and strength achieved by heat treatment made surprisingly little difference to the rates of flank wear on tungsten-titanium carbide tools as shown in Figs. 32 and 33. At low cutting speed, the rate of wear of tungsten carbide tools was not greatly different from that of tools containing titanium carbide. It was often somewhat lower. As cutting speed was increased, however, a point was reached where the rate of wear on tungsten carbide tools rapidly increased and became many times as great as on the tools with titanium as shown in Fig. 34. The higher the tensile strength, the lower the cutting speed at which this change occurred. Since this sudden increase in rate of flank wear occurred only on tools without titanium, it is tempting to assume that a reaction between the steel and tungsten carbide occurs similar to that occurring in cratering wear, but there is no direct evidence of this. A further study of the conditions under which this change occurs could lead to a better understanding of the nature of flank wear. Such changes in rate of wear are another reason why the tools containing titanium carbide are preferable for most machining of steel.

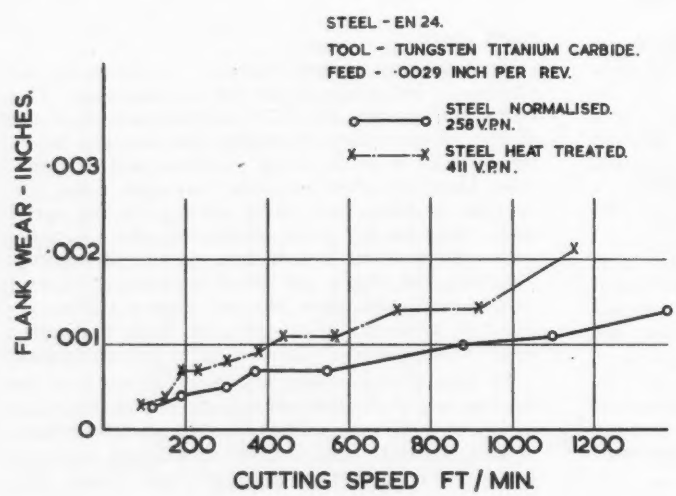

Fig. 33. Effect of heat treatment of steel on flank wear after one minute cutting time; tungsten-titanium carbide tools.

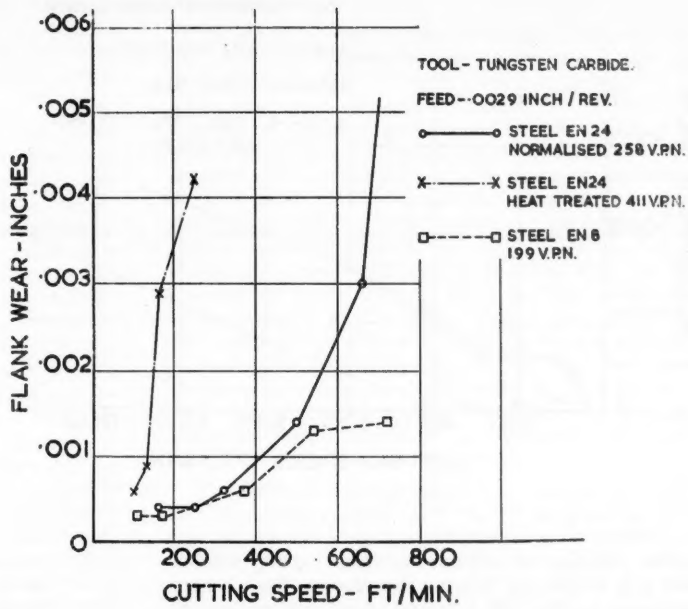

Fig. 34. Effect of heat treatment of steel on flank wear after one minute cutting time; tungsten carbide tools.

The rate of flank wear on austenitic stainless steel was much higher than on any plain carbon or low alloy steel tested — see Fig. 35. In longer time tests the differences in rate of wear became more pronounced. Over most of the cutting range tungsten carbide tools showed lower rate of wear than those containing titanium carbide. The difference may be in the ratio of more than 2 : 1. Only at the top of the speed range did the tungsten carbide tools wear more rapidly. The rate of flank wear on the "martensitic" stainless steel was not much different from that of plain carbon or low alloy steels. The large difference between these and the austenitic stainless steel was therefore most probably due either to the high nickel content of the latter or to its austenitic structure.

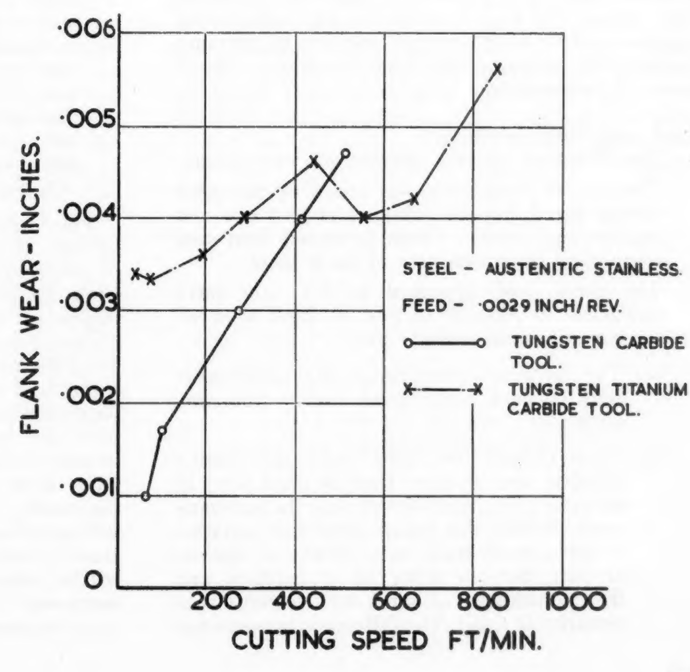

Fig. 35. Flank wear of tungsten carbide and tungsten-titanium carbide tools after cutting austenitic stainless steel for one minute.

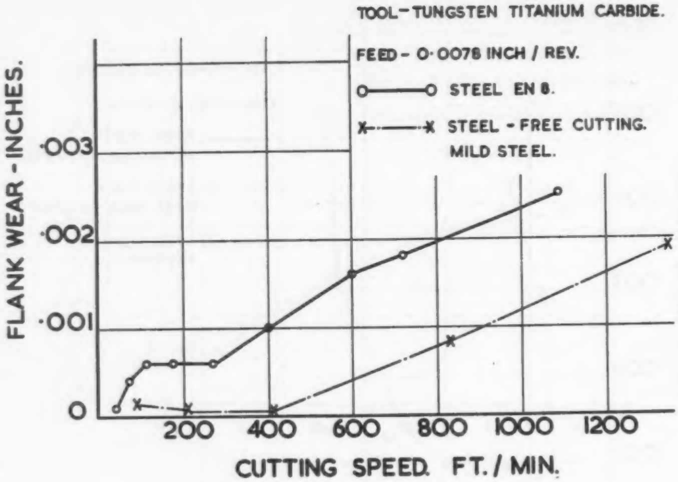

Fig. 36. Comparison of flank wear after one minute cutting on steel En8 and on free cutting mild steel.

The addition of sulphur in "free cutting steels" had a very great effect on the rate of flank wear, as shown in Fig. 36 for mild steel. After longer cutting times the great reduction in flank wear caused by sulphur became even more marked. The benefits of sulphur addition extended over the whole range of possible cutting speeds and feeds.

Flank wear in cutting cast iron increased with cutting speed and the rate of increase became greater after build-up disappeared. At low speed and feed, where a large built-up edge was formed, there were conditions where this gave almost complete protection to the tool and hardly any wear could be detected over long periods of time when cutting clean metal. The rate of wear was least when using tungsten carbide tools and the addition of titanium considerably increased the rate of wear — by a factor of two or more.

flank wear measurement

The following general observations were made :

1. The rate of flank wear was raised by increased cutting speed, but the influence of feed rate was smaller and erratic. Often increased feed rate resulted in decreased rate of flank wear.
2. The steels used appeared to fall into three categories in relation to rate of flank wear on tungsten-titanium carbide tools :
   (a) The austenitic steel containing nickel gave rates of flank wear much higher than any others.
   (b) Plain carbon, low alloy steels and ferritic stainless steel all gave rates of flank wear of the same order, much lower than the austenitic steels. Within this group there was variation in the rate of flank wear from one steel to another, but the influence of hardness and the percentage of alloying elements was remarkably small. The difference between two bars of steel to the same specification could be as great as the difference between the hardest and softest steels tested.
   (c) High sulphur steel gave rates of flank wear much lower than the corresponding steels of normal sulphur content.
3. The effect of titanium carbide in the tool material on the rate of flank wear with plain carbon and low alloy steels depended on the cutting speed, feed and the hardness of the work materials; tools without titanium carbide had flank wear rates similar to, but usually lower than, those of the tools with titanium carbide, over the whole cutting range tested. With increasing hardness of the work material this was only true at low speed and feed, and there was a critical point above which the rate of flank wear on the tungsten carbide tools increased very rapidly. The higher the hardness of the work material, the lower the speed at which this change took place.

These observations were made for the most part on tests of only one minute cutting time, but some of the conclusions are so definite that it is worth while considering if they throw any light on the nature of flank wear. It is known [13] that the temperature of the tool tip, as measured by tool-work thermocouple, increases both with the cutting speed and with the feed rate. The rate of flank wear increases with cutting speed but often decreases with the feed rate. Flank wear is, therefore, not directly related to the temperature near the cutting edge of the tool tip. With increasing cutting speed the cutting force and the thrust force decrease, while with increasing feed, both forces increase. It follows that the rate of flank wear is directly related neither to the temperature nor to the tool forces. Although increasing the hardness of the work material by heat treatment resulted in some increase in the rate

of wear, the increase was relatively small. But two factors having great influence on the rate of wear appeared to be chemical composition of the work material and tool material and the presence of a built-up edge on the tool.

As regards chemical composition of the work material, the element having the greatest effect was sulphur which was present in the form of manganese sulphide and greatly reduced the rate of flank wear. (Lead may have a similar effect). The elements chromium and nickel played a relatively small part unless nickel was present in sufficient quantities to give an austenitic structure, when the rate of wear increased greatly. There were also some relatively large differences in rates of wear of steels with no obviously significant differences in composition or structure, which so far have not been explained.

It is possible for the alloying elements introduced into steel to exercise a direct effect on the rate of tool wear by forming compounds which act as abrasives (e.g., Al_2O_3 or TiC) or as lubricants between the tool and the work material (e.g. MnS). The evidence suggests, however, that the direct effects are important only under certain limited cutting conditions. There is, however, another and probably more important way in which alloying elements can exert an indirect influence on tool wear and machinability.

Micro-examination of sections through the built-up edge has suggested the process by which this may protect the tool surfaces from wear. The complete absence of tool wear under some conditions suggests that, under these conditions the flow is entirely within the metal being cut, the layer of metal in contact with the tool surface being stationary. Under other conditions the metal in contact with the surface is stationary on part of the interface and in motion over the remainder. It is concluded from this that *the nominal surface velocity of the work material relative to the tool may bear no relation to the true velocity at the interface on the rake or flank surfaces.* It is at this interface that wear takes place and it is the relative movement at this interface or very close to it (a distance of the order of a few atomic diameters) which is of importance in relation to wear.

The picture thus built up is of a complex pattern of flow around the cutting edge, changing with the cutting conditions. The types and rates of wear depend on the details of this flow pattern. It seems probable therefore, that elements such as sulphur and nickel exert their greatest effect by altering this flow pattern, nickel by forming austenite and sulphur by forming manganese sulphide acting largely as an "internal lubricant" in the steel.

Superimposed on the flow pattern and related to it is a pattern of steep thermal gradients. Until more is known of the complex patterns of flow and temperature in the work material near the cutting edge, it is unlikely that it will be possible to account for the observed rates of wear in terms of the properties of work material and tool and the measured cutting forces.

conclusions

The study of worn cemented carbide tools with the aid of the microscope has shown the main types of wear, and factors affecting wear, including flank wear, the built-up edge, cratering, deformation, mechanical chipping and thermal cracking. The first four of these wear factors have been studied separately and their occurrence over a wide range of conditions on a number of ferrous materials has been investigated by a series of short time cutting tests. The results have been presented in the form of machining charts, in which cutting speed and feed rate are the co-ordinates to logarithmic scales and the occurrence of build-up, cratering and deformation is plotted. The value of such charts in summarising and ordering a large amount of information on tool wear and machinability has been demonstrated. If used with care such charts can also be of assistance in selecting optimum cutting conditions and predicting tool performance under given conditions.

The flank wear occurring in short time cutting tests has also been studied. The results suggest that the rate of wear is greatly influenced by the pattern of temperature distribution and flow of the work material around the cutting edge. Work on this problem is required in order to relate the rates of tool wear, the form of the built-up edge, etc., to the properties of the tool and work materials.

acknowledgments

The Author wishes to express his thanks to the Directors of Hard Metal Tools Ltd. for permission to publish this Paper, and to Mr. A. E. Oliver, F.I.M., Chief Chemist and Metallurgist, for his advice and for his support and encouragement in pursuing this line of work for a number of years. The Paper would not have been possible without the painstaking work of a number of colleagues at Hard Metal Tools Ltd. and Wickman Ltd. In particular, the Author would like to acknowledge the work of Messrs. G. A. Wood, A.I.M., F. Pauling, N. Brown and D. Twigger. The Meehanite and stainless steel bars used were supplied through the courtesy of The Meehanite Corporation and the Brown-Firth Research Laboratories respectively.

A LIST OF REFERENCES
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APPENDIX

General references on the subject of electroforming are :

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Some of the processes described in this Thesis may in certain cases be covered by patents. Included with these is A.S.R.E. Patent, Application No. 32073/56, Manufacture of Waveguide Components by Metal Spraying; also Elliott Brothers (London) Ltd., Patent No. 144150, Improvement in the manufacture of Waveguide Components.

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microwave instrumentation

by W. E. Stimson, A.M.I.Prod.E.

A thesis describing production problems encountered during the evolution of a new instrument

THE manufacture of microwave instruments and components has necessitated the development of a number of special techniques and methods of construction not usually met in instrument manufacture. This is particularly true of waveguide instruments, where the main problem presented to the engineer is the processing of material (mainly metal) to produce internal surfaces of various shapes and sizes to close limits and free from surface defects or blemishes. In the case of the production of precision measuring instruments, where the highest standard is required, the solution of the problem becomes proportionately more difficult.

It is essential that the Production Engineer has some basic knowledge of the function of waveguides to assist him in his approach to these difficulties. Microwaves are electromagnetic waves with a short wavelength, in comparison with which the radio waves of the normal broadcast band are very long, and light waves are extremely short.

	Wavelength	*Frequency*
Medium Wave Transmission	300m	1 Mc
Television Transmission	6m	50 Mc/s
Microwave Transmission	3×10^{-1} —10^{-3}m	10^{3} Mc/s —3×10^{5} Mc/s
Yellow light ...	6×10^{-7}m	5×10^{8} Mc/s

At frequencies of 1,000 megacycles and upwards it is possible to transmit the waves down pipes or waveguides, as they are called, in much the same way as sound is sent along voice tubes. This method is used because there is less loss of power in a length of waveguide than in the same length of wire. Although the waves are mainly travelling in the space inside the waveguide, there are also radio frequency currents flowing in the inner surface skin and penetrating into the metal by only a few micro inches.

Without going into the theory of microwaves it is possible to consider certain aspects of their characteristics by means of analogy. For example, microwaves in some respects behave the same as light waves; they travel at the same speed, they can be reflected by certain materials, pass through some materials, or be absorbed by others. Insofar as the aim is to transmit microwave power through the instrument with the minimum loss, it will be appreciated that reflection absorption and leakage must decrease its efficiency. In practical terms, the following manufacturing faults are detrimental to the performance of an instrument and can cause an instrument otherwise within mechanical tolerances to fail in electrical test :

1. Scratches, bumps, ripples, burrs and foreign bodies, such as blobs of solder, etc., in the waveguide. Any of these faults will cause *reflection*.
2. Distortion of the waveguide, such as can occur on soldered assemblies, or careless clamping of workpiece during processing will cause *reflection*.
3. Scratches on the face of the waveguide connector or any unevenness of the face, will cause a *leakage*.
4. Damage to the waveguide window can cause *leakage* and *reflection*.
5. Burrs, or the removal of burrs by chamfering of the waveguide window, will cause *reflection*

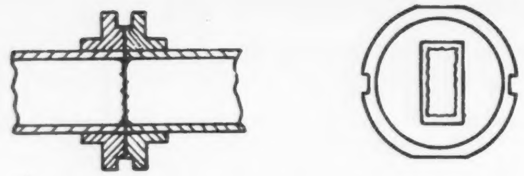


Fig. 1. Flanged waveguides assembled with burrs on the windows causing reflections.

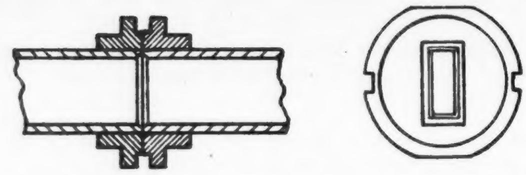


Fig. 2. Flanged waveguides assembled with burrs removed by chamfering, producing a small cavity which causes reflection.

(Figs. 1 and 2). This is a most important point. There must be no interference in the microwave path from one piece of equipment to another (Fig. 3).

6. Occluded fluxes and corrosive products such as may appear in a soldered joint will cause *absorption.*

An appreciation of these points will assist the Production Engineer to realise the importance of ensuring that at all stages of manufacture there is a complete understanding by those concerned of the exact requirements. This means the careful editing of drawings, production of special manufacturing process sheets and layouts.

the evolution of a new instrument

This will proceed along the following lines: The Physicist, who is concerned primarily with fundamentals, will define a configuration of electrically conducting surfaces which will provide a solution to the requirement of the specification. This basic information will be described in absolute dimensions.

The Microwave Development Engineer will calculate the permitted dimensional tolerances in the configuration. Experimental models will be used for this purpose. The order of close tolerance dimensioning which is commonly called for is $\pm$ 0.0001 in. in WG 22, $\pm$ 0.0005 in. in WG 16 and $\pm$ 0.002 in. in WG 10.

The Mechanical Design Engineer, in consultation with the Production Engineer, will lay out a structure composed of solid pieces which, when assembled, will realise the required configuration of internal surfaces. It is here that the Production Engineer's knowledge of the capability and the limitations of labour and machine tools, plus an assessment of the various special processes and techniques, will play an important part.

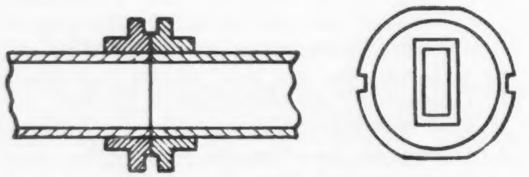


Fig. 3. Correctly deburred waveguide window produces a continuous uninterrupted waveguide wall.

A prototype model is then manufactured in the experimental workshop from these drawings, and it is examined by the Mechanical and Microwave Development Engineers in considerable detail, and subjected to comprehensive tests. Any necessary modifications to the design are made and when satisfactory results are obtained the drawings are brought into line and passed to the Production Engineer for the development of a detailed production plan. The plan is tested by the means of a short pre-production manufacturing run, and any further modifications arising in the light of a study of this work are incorporated into the drawings. A comparison of different processes can be conducted at this stage and the information finalised for future production.

various methods and techniques

Waveguide can be produced by a number of different processes. The process to be employed in a particular case is to a large extent dependent on the required electrical performance of the instrument and the complexity of the design. A combination of processes often produces the best results. These processes include:

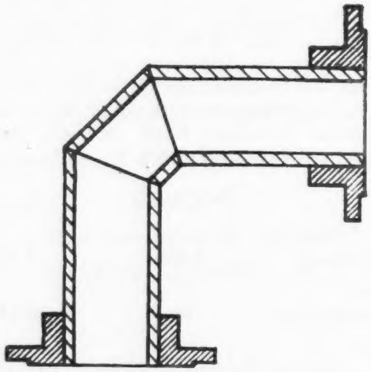


Fig. 4. Corner fabricated with extruded waveguide with flange connectors.

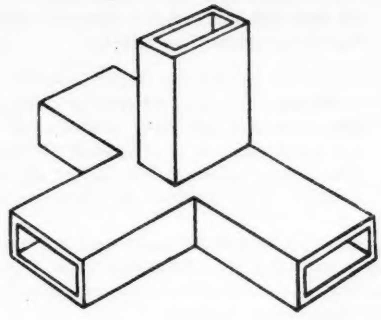


Fig. 5. Hybrid tee fabricated with extruded waveguide without flange connectors.

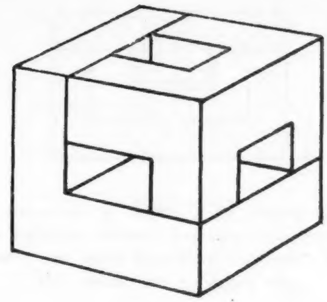


Fig. 6. Hybrid tee fabricated with two dissimilar parts machined from bar material.

extrusion

Extruded waveguide in the common sizes is manufactured by a number of firms and is obtainable in copper, brass and aluminium. The standard sizes range from 0.034 in. $\times$ 0.017 in. to 18 in. $\times$ 9 in. Precision WG 16 rectangular waveguide (0.900 in. $\times$ 0.400 in.) is made with an 0.050 in. wall and to limits of $\pm$ 0.002 in. This is quite adequate for some requirements. It is also possible to obtain from certain suppliers short lengths of extruded waveguide to a limit of $\pm$ 0.001 in. in the bore. Needless to say, this waveguide is considerably more expensive as it has to be specially drawn and selected. Extruded waveguide can be formed to certain shapes such as tapers and transitions by swaging.

fabrication

This is a method of waveguide construction which lends itself to a wide variety of applications and can incorporate a number of other processes :

1. The fabrication of extruded waveguide by brazing or soldering together machined sections is common practice. This has particular advantages insofar as the outside dimensions of the waveguide are the correct sizes for fitting the flange connectors and machining is reduced to the minimum. Corners and hybrid tees are good examples (Figs. 4 and 5). Where there are a number of joints close together it is advisable to use a range of solders with different melting temperatures. Distortion caused by heat is the main disadvantage of this process, though consistently good results are obtained by induction heating.

2. The fabrication of machined part-pieces from bar or cast materials is a more accurate method. Fig. 6 shows an example of a hybrid tee where close limits are obtained by a normal machining process. Fig. 7 illustrates a precision bend made from two mirror image sections profile milled. This work can be carried out to limits of $\pm$ 0.0005 in. While it is obvious that a superior product is obtained by this method, a disadvantage is that a means of connecting the assembly to other apparatus must be devised. This would involve the manufacture of flange adaptors, the windows of which would have to be matched to the accuracy of the assembly, or machining suitable flanges on the workpiece. Either method is expensive.

3. Another method of fabrication by which a high degree of accuracy can be obtained is shown in Fig. 8. A waveguide 11 in. long has been produced by this method accurate to $+$ 0.0002 in.,

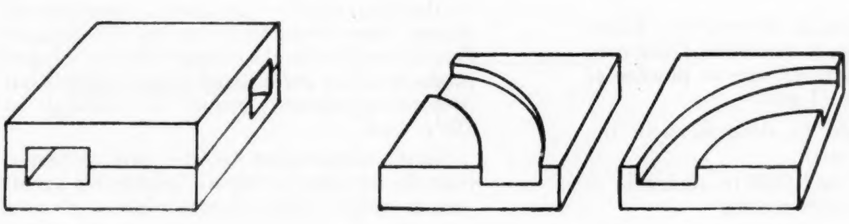


Fig. 7. 90°E plane bend fabricated with mirror-image parts machined from bar material.

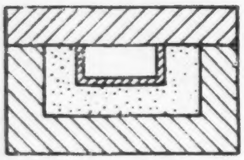


Fig. 8. Cross-section of a length of precision waveguide fabricated with electroformed channel moulded into a cast channel with Cerro-cast or loaded resin, and with a ground plate supplying the fourth side.

but the close control required at all stages makes this an extremely expensive process. It is illustrated here as an example of a method which has possibilities, but is not at the stage where it is an economic proposition.

precision casting

In spite of the manufacturers' claims, it would seem that an accuracy better than $\pm$ 0.003 in./in. cannot be consistently maintained. While not sufficiently accurate for precision instruments, components can certainly be made by this method, though it would be advisable for the waveguides to be made to the bottom limits and the windows 'sized' as described later in this Thesis.

The 'lost mercury investment casting' has possibilities. A considerable amount of effort has gone into producing waveguide components by this process, but the accuracy achieved is no better than by other precision processes and the tooling costs could well be higher.

Satisfactory components, but to no greater accuracy, are produced by a process that includes a plaster core formed by an accurately machined metal core box for the interior shape and shell moulding for the outer contours. Here again the initial tooling cost is high.

metal spraying

The process of metal spraying has considerable possibilities. The basic principle is the same as with electroforming in that the metal is deposited on to retractable formers. The equipment needed comprises:

1. Spray booth, spray gun, compressed air and oxy-acetylene gas.
2. Metals in a form suitable for spraying. There is a large range of metals available. These may be obtained in the form of wire or powder as required by the make of gun.
3. Formers. These must be designed with the following points in mind:
   (a) The former must be 0.0006 in. undersize to allow for the lacquer coating.
   (b) The former must be longer than is required so that the ends of the sprayed component can be machined to length.
   (c) The material for the former must be able to withstand the heat of the spraying process. Brass or stainless steel are suitable metals. In some cases it is advisable to make provision for passing air or water through the former. This hastens the spraying process.
4. Lacquer. The formers are lacquered prior to metal spraying. The lacquer acts as a protective coating for the mandrel as well as a bond for the initial coat of metal.

Technique. The former is degreased. The lacquer is applied to a thickness of 0.0003 in. and stoved. The lacquered former is then sprayed with molten metal. If a soft or expensive material is required it need only be sprayed 0.005 in. thick. Steel or brass metal may then be used to build up the component to the required size. If there is no provision for cooling the former by air or water, the component must be allowed to cool a number of times before the process is completed. The former is extracted from the component and a solvent is used to remove the lacquer.

Disadvantages. The deposited metal is more porous than cast metal and has a tensile strength of about 25% of that of the wrought metal. The tensile strength can be increased to 60% by vacuum impregnation with a suitable resin. The inside surface is not so good as that obtained by electroforming.

electroforming

Electroforming is a process by which certain internal forms can be made to very close limits and more complicated shapes to rather wider limits. Basically it is a process of electro-depositing a suitable metal (copper is most generally used) on to a mandrel or former of the required shape. The mandrel is then extracted or dissolved according to the material from which it is made, or remains as part of the component. The equipment needed comprises:

1. Plating vats with immersion heater thermostatically controlled, filters (sintered glass) and power supply (D.C. usual operating voltage 1.3 - 1.5v).
2. Electrolyte for copper forming may be of the acid/copper sulphate or the copper/cyanide formulae. With the latter the periodic reversal of the current flow can give a very smooth deposit free from build-up on the corners Periodic reversal in the copper sulphate solution produces a fine grain tough copper deposit but does not significantly reduce the build-up on the corners.

   Some improvement in the surface results from the inclusion of organic brightening agents such as molasses in the copper sulphate solution,

but this improvement is usually accompanied by an increase in the internal stresses in the material, and by a reduction in electrical conductivity.

3. Anodes — commercially pure copper produced by the arsenic reduction process, supplied in extruded bars.

4. Cleaning agents — copper cyanide, potassium cyanide, detergents, distilled water.

5. Extractors for removing retractable formers from electroforms. These could be hydraulic or screw thread type.

6. Formers — the accuracy of an electroform is limited to the accuracy of the former and that in turn is determined to a measure by the material from which it is made. Formers may be classified under three main headings;
(a) *Retractable formers*. These are restricted in shape, but complex forms can be produced by fabricating a former from a number of sections each of which can be removed independently. Such a former would be made to produce a hybrid tee (Fig. 9).
Normal shapes for which retractable formers are suitable include: precision waveguide, tapered waveguide, horns and rectangular-to-round transitions.
The manufacture of retractable formers is extremely expensive, requiring labour and equipment of the highest toolroom order. Apart from good dimensional accuracy, the formers must be highly polished to facilitate their extraction.
The material for these formers must be durable and corrosion resistant. Glass is very good but of limited use. Glass formers must be coated with an electrically conductive material (silver sprayed) to make a suitable cathode.

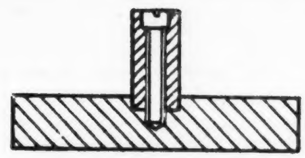


Fig. 9. Collapsible former

Austenitic chromium nickel steel alloys (18% chromium, 8% nickel, EN58 range) have proved to be the best materials to date. As virtually non-magnetic materials they have certain manufacturing disadvantages, plus an instability that becomes apparent when machining the slender formers required for the WG 22 and millimetre wavelengths.

Experiments have recently been made with titanium. Four millilitre rectangular waveguide formers have proved much easier and, therefore, cheaper to manufacture than with EN58, due to the inherent stability of the material. Comparable electroforms have been produced and there would appear to be every likelihood of the formers in this material having a longer life.

Perspex plates and "stopping-off" materials such as Detel are used to restrict the electrodeposition of metal to the required surfaces of the former (Fig. 10).

When designing a metal former the further manufacturing processes must be considered.

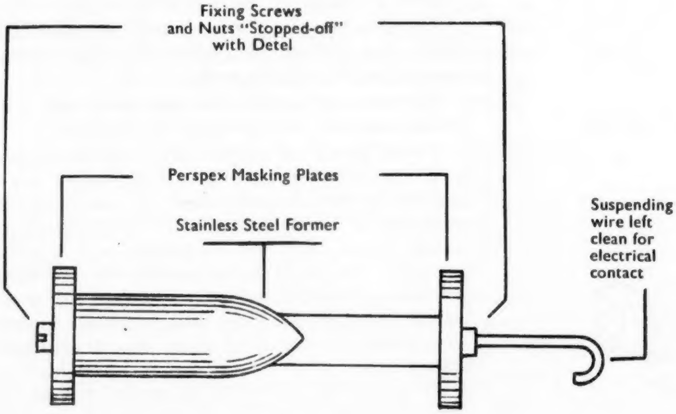


Fig. 10. Former with masks assembled for electro-plating

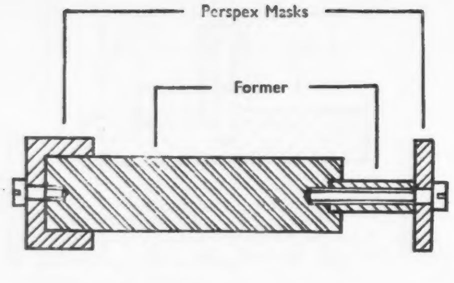


Fig. 11. Collapsible former with section masked for chucking to facilitate machining operations prior to extraction

The majority of electroforms require machining to suit other details of the assembly and the Production Engineer has to decide whether it is better to carry out this process before or after the extraction.

Turning centres may be included or a length of the former masked by Perspex to provide for chucking (Fig. 11). When considering the use of a former as a machining mandrel, two factors must be borne in mind: the electroform must be processed as soon as possible after removal from the vat, and a larger number of mandrels would be required for efficient batch production.

(b) *Expendable formers.* These formers can be produced by two methods:

(i) Machined formers — Perspex is a very suitable material. The finish must be smooth and free from blemishes. The former is cleaned and sprayed with a silver solution prior to electroforming. After building to the required thickness the Perspex is dissolved in chloroform.

(ii) Moulded formers — a plastic material such as wax is required for this process. A mixture of polyethylene (one part) and paraffin wax (two parts) is suitable. (This solution loaded with French chalk has produced excellent results but has tended to clog the injection machine.) Additional equipment includes: *Wax Moulding Machine* with electric heater and Variac Control; *Gun* for silver spraying (PATRA); *Spray Booth* with extractor fan; *Solutions* for cleaning, sensitising and silver spraying; *Moulds:* these are made of brass to very close limits, with removable sections dowelled and bolted.

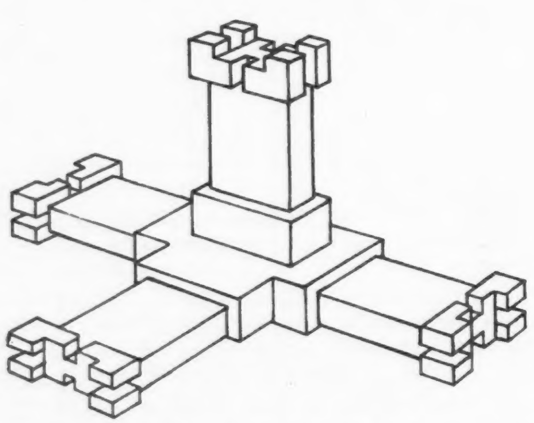


Fig. 12. Moulded former with faces relieved prior to the second charge of wax

For wax moulding, the wax in the reservoir of the machine is heated until it is just plastic; $60° \pm 2°$ for small mouldings; higher for larger mouldings such as WG 16 hybrid tees. If the temperature is too high, excessive shrinkage will take place and if too low, the resulting moulding will have a poor finish.

The mould should be thoroughly cleaned; the sections separately heated and bolted tightly together. The mould is then screwed to the reservoir and the wax rapidly injected and pressure applied (about 1,000 - 1,500 p.s.i.) until the wax has set. For small mouldings this should take 2 - 3 minutes. The mould should be immediately removed from the machine to avoid becoming heated by conduction.

In spite of the tightness with which the mould has been assembled there will be a spillage at all the joints, which will produce flashings on the moulding. These must be removed with great care.

A silver-plated wire rough knurled at the end is heated and pushed into an undersized hole made in the moulding. This is used for suspending the moulding during plating. The moulding is then cleaned with a solution of 10% comprox, washed with tap water, sensitised with stannous chloride solution, washed again with tap water, and swilled in distilled water. Spraying with silver follows, without allowing the sensitised moulding to dry.

The moulding is then washed with distilled water and, before the silver film has dried, inserted in the plating bath.

After the electroform has been produced, it is heated and the wax removed by melting.

To produce good quality large wax mouldings it is necessary to modify the moulding procedure to two stages. First, a moulding is produced as described above. An inspection would show that the moulding was poorly produced. It could have cavities on the face of about 0.010 in. The moulding is then relieved around its faces with channels giving free access to the inlet (Fig. 12). It is then assembled as a core into the mould which is attached to the reservoir. A second charge of wax is made, filling all the relieved faces and channels. The remaining operations follow the pattern as detailed above. Electroforms can be made to 0.001 in. by this method.

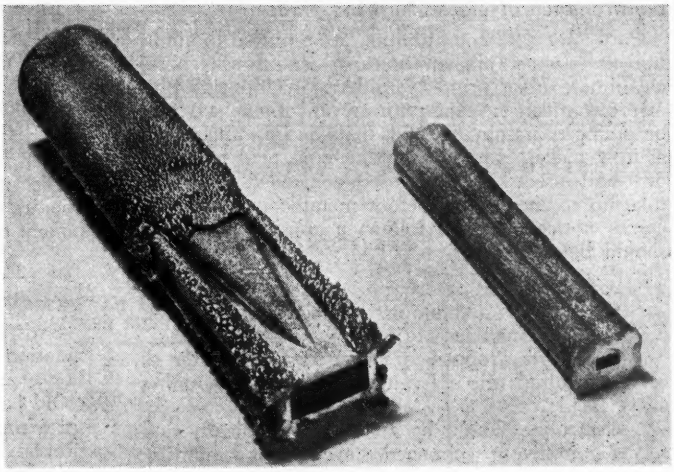


Fig. 13. On the left is shown an example of the nodule formation caused by excessive current density (WG 16). The bath was also contaminated, thus adding to the gruesome appearance of this electroform. On the right, an example of stress-free electroforming (WG 22)

(c) *Permanent formers.* These formers are made of a dielectric material, cleaned and silver sprayed before electroforming. As the former remains an integral part of the instrument or component, a much lighter deposition is adequate. It is also possible to produce complicated shapes in one unit.

The rate of electro-deposition can be regulated to suit requirements. To obtain the best results the electroforming must take place in stress-free conditions, where there is a low current flow producing a deposit of about 0.0005 in. per hour.

An increase in the deposition rate to 0.002 in.-0.003 in. per hour results in the formation of significant internal stresses in the formed materials when using the copper sulphate solution. The temperature of the electrolyte is critical when electroforming at this rate and must not fall below 45°C. Under these conditions it is necessary to agitate the electrolyte; this can be accomplished by making a mechanical contrivance which will cause the suspended formers continually to oscillate in the solution. It has been found that molasses acts as a smoothing agent in a high rate bath, but its action is not as yet fully understood.

The disadvantages of high rate electroforming are porous deposit, increased nodule growth (Fig. 13), occlusion of copper oxide, coarse crystal structure and internal stresses.

special jigging

It is often impossible to obtain an even deposit of metal with complicated former shapes. This trouble appears in two forms :

1. *Excessive build-up on corners.* This can be dealt with by removing the electroform from the vat at various stages of its formation and removing the excess material by filing or machining. Alternatively, the former can be jigged to carry " thieving " bars at the appropriate positions (Fig. 14). These bars are made of suitable conductive material and are wired to the former, becoming part of the cathode and thus diverting or " thieving " deposit from the adjacent area of the electroform. Dielectric " shading " bars are also effective.
2. *Inability to "throw" into corners.* In this case similar jigging is resorted to, but copper bars placed at the strategic positions are wired as anodes and supplement the flow at these points (Fig. 15).

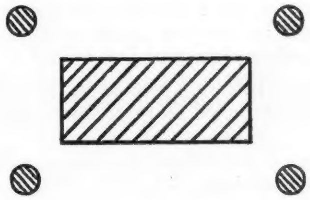


Fig. 14. Sectional view, showing arrangement of " thieving " bars around former

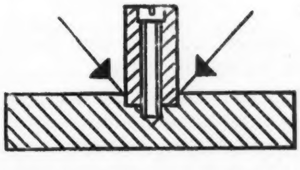


Fig. 15. Sectional view, showing local anodes arranged to assist the " throw " into the formers

maintenance of electroforming plant

Particular care and attention are required to maintain the plant in efficient working condition. General cleanliness is a prime consideration. Special precautions must be taken to prevent the electrolyte becoming contaminated with metallic substances such as iron, nickel, chromium and arsenic, acid solutions, dust and insects. With a closely controlled vat it will take up to six months before metallic pollution becomes noticeable. The following routine procedure should be adopted:

- vats should be covered;
- filter pumps and motors checked daily;
- filters cleaned weekly;
- electrolyte "topped-up" with distilled water as required; the pH value checked before adding acid;
- electrolyte should be analysed periodically and completely changed every six months, individual vats treated in rotation.

It is suggested that a log or day book is kept and a record made of loadings and all routine cleaning procedures as well as details of irregularities.

Electroforming procedure for stainless steel formers

1. Suspend former on the anode bar in the cyanide bath for 2 - 3 minutes. Ensure that all the cyanide solution has drained off into bath before removing the former.
2. Place former under clean running water for about 3 minutes.
3. Place former in potassium dichromate solution tank for not less than 2 minutes.
4. Wash off surplus solution in distilled water.
5. Suspend former immediately in plating bath.
6. After removal from the bath the electroform is washed in running water and is then ready for further processing if required.
7. The electroform is heated in hot water and the former extracted by mechanical means.

Electroforming procedure for non-metallic formers, Perspex, wax or dielectrics, etc.

1. Clean with detergent or a comprox solution.
2. Wash in distilled water.
3. Silver spray.
4. Immediately transfer to copper plating bath either for 0.001 in. protective coat prior to temporary store or for building up to requirements.
5. After removal from the bath the electroform is washed in running water.
6. Dissolve expendable formers by the application of heat, or with the use of solvent.

The principal advantage of electroforming lies in the fact that normally inaccessible internal surfaces can be defined in terms of the accessible external surfaces of a forming mandrel. The disadvantages are:

Electroforms take a long time to produce and output is restricted to the number of formers and the capacity of the plating equipment. Retractable formers are expensive to produce. Capital outlay in plant and formers is relatively high and maintenance and depreciation costs will also be high even when the plant is lightly loaded.

Electroforms invariably require further machining operations before they can be assembled into a component or instrument.

special methods

Satisfactory results are often obtained by the combination of two or more of the foregoing processes. For example, a 0.010 in. deposit by electroforming could be built up to the required thickness by metal spraying, thus reducing the time of completing the process. A 0.020 in. thick electroform can be moulded into its component parts with Cerrocast or loaded Araldite, thus reducing machining costs.

Other methods and processes that can be employed in special circumstances include:

- electroforming on to other components;
- broaching for short waveguide lengths;
- hobbing short very accurate waveguide — this process can be expensive in material and subsequent machining operations due to the large blanks required;
- spark erosion — this process is particularly useful for forming small apertures of complex shape such as are required for directional couplers, etc.

tolerancing and sizing

One of the aspects of microwave design is that the reflection of power from an unavoidable irregularity can often be prevented by placing a second irregularity in the right place. Similarly, it is possible to offset the effect of the unacceptable dimensions of one plane of a rectangular waveguide window by an adjustment to the other plane. As the safe tolerancing by normal practice demands an accuracy higher than is needed, and the rigours of processing to very close limits can produce a heavy toll, a method of chart tolerancing has been devised.

Numbered tolerance charts are produced for each acceptable range of dimensions in rectangular waveguide. While the drawings of detail parts are toleranced in the normal manner, the appropriate assembly or sub-assembly drawing carries the tolerance chart number. The instrument maker, when checking the waveguide dimensions against the chart, is able to deduce with ease the correct amount of adjustment to make if it is required. Complementary to the tolerance charts special hardened steel sizing mandrels can be made (Fig. 16) for each chart. These mandrels are correctly tapered in each plane so that the correct dimensions obtain at any position of the taper. The use of these mandrels for sizing waveguides eliminates uncertainty and reduces manufacturing time.

TOLERANCE Nº	DIMN W	DIMN T	FOR REFERENCE DIMN w	DIMN t	ANGLE θ	ANGLE α
1 MPS 9	·9025	·4012	·8975	·3988	8′-36″	4′-17″
2 MPS 10	·9030	·4018	·8970	·3982	10′-18″	6′-11″
3 MPS 11	·9040	·4034	·8960	·3976	13′-44″	11′-30″
4 MPS 12	·9050	·4050	·8950	·3950	17′-11″	17′-11″

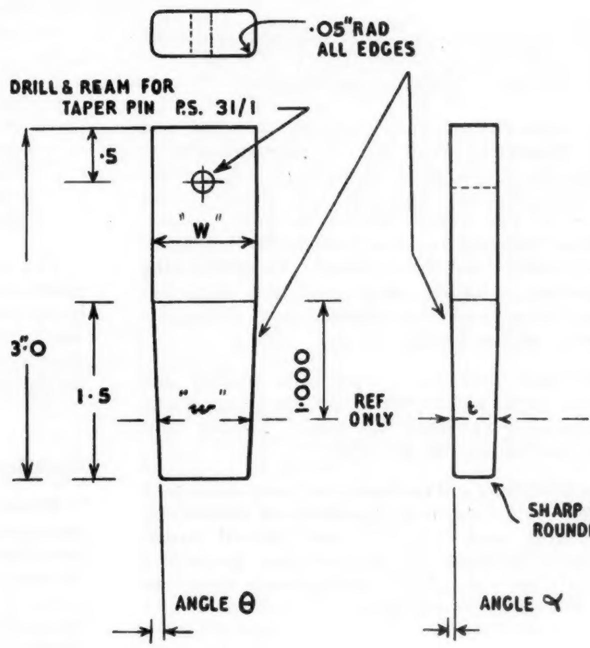


Fig. 16. Sizing tool for WG 16 windows (The angles are accentuated for clarity)

an attempt at an assessment

In view of the multiplicity of processes and the complexity of requirements an objective comparison covering all aspects of microwave instrumentation would be a very difficult and lengthy undertaking, but one aspect, the comparative precision of the process discussed, can be illustrated as in the following table :

Process	*Tolerance*	*Comments*
Electroform (retained dielectric former) ...	As former	Expensive machining
Electroform (retractable former)	± 0.0001 in. of former	Expensive tooling and machining
Fabrication precision machined parts ...	± 0.0005 in.	Expensive machining
Metal spraying	+ 0.001 in. — 0.0004 in.	Moderate tooling and machining
Electroform (expendable former) 2-stage	± 0.001 in.	Expensive tooling and machining
Electroform (expendable former) 1-stage	± 0.002 in.	Expensive tooling and machining
Fabrication extruded waveguide induction brazing	± 0.002 in.	Moderate tooling
Precision casting	± 0.003 in.	Expensive tooling and machining
Fabrication extruded waveguide torch brazing	± 0.004 in.	Cheap tooling

The factors influencing the choice of process are summarised as follows:

Close tolerances limit the choice of process and likewise the wider the tolerance the larger is the number of alternatives.

The internal configuration can also determine the process.

Alternative processes may be divided into three groups:

1. *Proprietary processes*—precision casting carried out entirely by specialists. Tool or part tool costs are the only additional consideration.
2. *Specialised processes* — metal spraying and electroforming. Work may be sub-contracted to specialist firms or it is possible for a small organisation to install their own plant. In this case the first consideration is the cost involved. Metal spraying requires a comparatively small investment and no upkeep. Electroforming involves a higher plant cost plus expensive installation and maintenance costs. Both processes require tooling.
3. *Standard processes* — precision milling and sheet metal techniques as used in swaging and fabricating extruded waveguide. Tooling costs are normal to the processes.

New applications and processes are being developed. These include the electrical deposition of aluminium, photo etching, and strip line and printed circuit techniques. Millimetre instrumentation presents a particular challenge which the engineer may well meet by revolutionary methods.

the special training of workshop personnel

Due to the complexity of the processes and the special techniques involved in the manufacture of microwave instruments, it has been found that even skilled instrument makers have taken some considerable time in acquiring the necessary ability and confidence to work at maximum efficiency.

To reduce this initiation period with all its implications of costly effort and wasted materials, it is suggested that each newcomer undergoes a period of training which could be arranged along the following lines:

1. On arrival he is presented with a booklet or pamphlet for information and reference. It will describe:
   (a) The function of microwaves
   (b) Special precautions to be taken during the manufacturing processes, with particular attention drawn to incompatibilities with what might be described as traditional practices, for example, deburring, with emphasis on the additional care that must be taken in otherwise normal processes such as brazing, soldering, etc.
   (c) The various processes and techniques and their application. (Processes and techniques would be described in detail on individual process sheets.)
   (d) The electrical effects of faulty workmanship.
2. A period of say, two weeks, practical training to a fixed schedule, which would be arranged to cover progressively all the points referred to in the handbook. The work would be closely inspected at all stages.
3. The training would end with the assembly of a test-piece which could be a standard instrument or component such as a crystal holder made from stock details or details made by the trainee. The results of the inspection and electrical test would be passed to the instrument maker as well as to the supervisory personnel concerned.

The cost of such a scheme would include the unproductive training time, extra supervision and inspection plus the cost of scrapped material. This would be off-set by a quicker return in higher productivity plus a reduction in rectification and scrappage-replacement costs.

mechanical inspection

Whilst the Inspection Department should be equipped with normal machining processes, it has been found that pneumatic gauges are absolutely essential for accurately measuring the internal waveguide. A separate gauge has to be made for each dimension. Fig. 17 illustrates an air gauge for rectangular waveguide, and Fig. 18 a gauge that can be pulled through a length of waveguide. "O" rings keep the jets correctly spaced and with the aid of a graduated tape a calibration of the waveguide can be produced. A development of this idea is the flexible gauge, which is designed for measuring bends and twists.

Only rubber inspection stamps should be used on waveguides and connectors. It is advisable to protect the connectors and windows with bungs or rubber covers. If these are not used during the manufacturing stages, they should certainly be fitted immediately after passing the mechanical inspection and only removed during the electrical test.

Inspection of most microwave instruments must be comprehensive and to avoid wasted effort as well as the possibility of an important feature being overlooked, an inspection schedule should be prepared by the Production Engineer in conjunction with the Mechanical Designer and Physicist.

The fact that an instrument conforms to the dimensional tolerances of the design and has been accepted by the mechanical inspector cannot be taken as proof that it will meet with the electrical specification. The critical dimensions of each instrument should be recorded for future use.

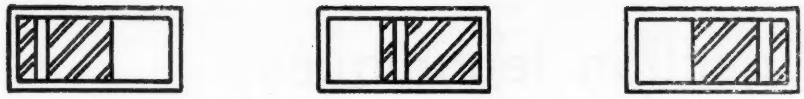


Fig. 17. Air gauge mandrel in waveguide illustrating the range of positions

electrical test

The basic equipment for the Electrical Test Department comprises:

Power Supply
Test Oscillator
Wave Meter
Calibrated Attenuator
Standing Wave Meter
Matched Load
Crystal Detector
Precision Variable Short Circuit
Short Circuiting Plate

An arrangement of these instruments is called a "Test Bench" and a complete Test Bench is required for each wave band.

A microwave component or instrument is usually designed to perform a particular function with the lowest co-efficient of reflection. The electrical test is designed to check the function and measure the reflection which should comply with the required specification. The following are examples of types of electrical test procedure:

1. *Complicated string of bends and twists.* Measure the overall reflection co-efficient at the desired frequency band. Also measure the transmission efficiency, that is, the amount of power that gets through the system.
2. *Crystal holder.* Measure the reflection co-efficient figure determined in the design specification. Measure the sensitivity of the crystal — direct current output for a given R.F. microwave power input.
3. *Variable short circuit.* The instrument's function is to reflect all the power. The electrical test is to check that all the power is reflected and measure the amount of loss.
4. *High power components.* After the routine tests at low power a further test at high power is made to ascertain whether the component will take the power without sparking or breakdown.

A test report is made for all instruments, and some instruments may require calibration charts.

Providing complete test schedules are available and a qualified Test Engineer is in charge, all this work can be carried out by young female laboratory assistants.

quality control

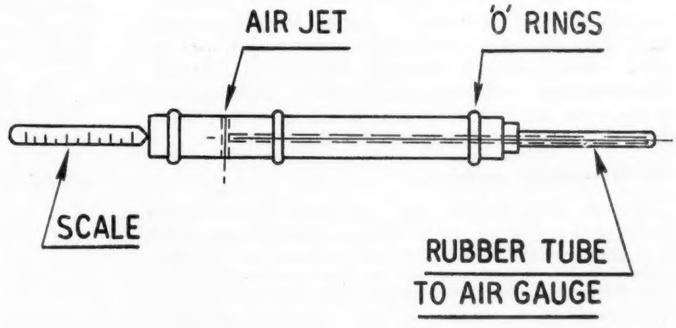
All mechanical inspection and electrical test reports are routed to Quality Control, where the information is collated and analysed. Thereby a check is made on the general standard of the product and a deterioration in quality readily recognised. It is possible to identify trends and establish causes. The engineers concerned are informed of all significant findings and with the aid of the accumulated data are able to effect an improvement of design and manufacturing efficiency.

conclusion

This Thesis is almost entirely concerned with one aspect of the problems of microwave instrumentation — the formation of internal surfaces to close limits and with fine finishes. Another problem of equal importance is to achieve mechanical movement of component parts within the close tolerances required. This is too large a subject to have been included.

(An Appendix is given on page 130)

Fig. 18. Air gauge for calibrating a length of waveguide



inspection techniques applied to the metrology of aerodynamic models

a thesis
by H. T. HILL, A.M.I.Mech.E., A.F.R.Ae.S., A.M.I.Prod.E.,
formerly Assistant Director,
Royal Aircraft Establishment.

WITH the increasing speeds of modern aircraft, and the related greater use of high-speed wind tunnels, together with the introduction of the " Free Flight " technique, there is not only a major model production problem, but also a parallel three-dimensional metrology problem.

To meet the increasingly complex demands, these models may vary from a simple half-wing to a complicated aircraft with adjustable control surfaces, and the provision for pressure plotting. Their sizes may vary from an included plan area of 6 in. × 4 in. to greater than 6 ft. × 4 ft.

This problem is as divorced from normal inspection procedure as is the manufacture of the models themselves from mass production.

The aim of model inspection is to define the actual three-dimensional shape of the model, rather than to accept or reject according to the drawing requirements and, for this special purpose, radically different inspection techniques are adopted.

Whereas in normal inspection the maximum reliance is placed upon comparators rather than upon fundamental measurement, in model inspection it is essential to use instruments with built-in basic scales; unfortunately, available standard measuring instruments have serious capacity limitations for this application, as well as being slow and fatiguing in operation.

This Thesis gives an appreciation of the problem confronting the metrologist, details of the present inspection methods employed by the major user of wind tunnel models, namely the Royal Aircraft Establishment, and thoughts on further developments to improve the accuracy and speed at which these three-dimensional models can be inspected.

the inspection problem

It has been stated that the basic inspectional problem is not so much to decide whether the model is within certain limits, but to provide a complete knowledge of the actual size and shape, in three dimensions, of the finished model. However, for the purposes of manufacture, certain tolerances are stipulated and an outline of these is to follow.

The degree of accuracy to which measurements must be known has risen rapidly with the development of high-speed techniques, and the metrologist is required to work to an accuracy considerably greater than the stated tolerances, the ultimate aim being the repeatable accuracy of checking all models to within 0.0001 in.

Aerodynamically, it is important that the shape of the aerofoil over approximately 15% of its chordal length from the leading edge is known with great accuracy, and that the whole aerofoil and model surface is free from waviness within the limits specified below. The thickness of the trailing edge must be uniform and in most cases is limited to 0.004 in. In addition the symmetry of the complete aircraft model is made an important feature.

tolerances

The name given to the overall general tolerance is an " Envelope Tolerance ". This defines a manufacturing limit as a marginal band, equally disposed either side of the design profile and within which the finished contour should be contained. In the past, the width of this band has varied from 0.003 in. on the smallest, to 0.010 in. on the largest models, but it has recently been suggested that the tolerances should bear some relation to the size of the model.

The Royal Aircraft Establishment Technical Memo. No.: Aero 460 (i) defines model accuracy and finish as follows:—

Relation of Accuracy to Size of Model

(i) " Skeleton " — linear accuracy $\frac{(2 \text{ to } 4) \times L}{10,000}$

angular accuracy $\frac{1^\circ}{50}$

(ii) " Rople " — linear accuracy $\dfrac{\pm L}{10{,}000}$

(iii) Finish — 10–15 microinches.

L = length of the model (wing span about $\frac{1}{2}$L wing mean chord about $\frac{1}{4}$L).

The above figures apply to the wing; double these figures are acceptable for the body.

Special difficulties

(i) The trailing edge will vary considerably in position if only the above tolerances are kept to. We are considering fixing the trailing edge in plan with the linear accuracies quoted above for the skeleton, together with a requirement that the blunt finish should not exceed $\dfrac{3L}{10{,}000}$ in thickness.

(ii) For pressure plotting models, it appears that the accuracy should be defined by slopes in the vicinity of the pressure holes rather than the dimensions. For consistency with the accuracy of tunnel flow, it has been suggested that the slope should be accurate to about $\dfrac{1}{1{,}000}$ (radians) over about $\frac{1}{10}$ in. This accuracy is an order higher than that demanded for the ordinates.

methods of inspection

The basis of inspection is the defining of points on the model in a predetermined grid pattern; the closer the grid, the better the appreciation of any variations from the designed contours.

The model is usually set up on a travelling carriage with its movement running parallel to the body axis or centre line. Attached to a separate fixture are two vertically opposed dial indicators set to zero at a theoretical horizontal plane common to the body axis or wing chord. A transverse datum is selected at a convenient position, either on or in front of the model (Fig. 1) which becomes the master datum and all dimensions taken parallel to the body axis are related to it. This transverse datum must be selected at a definite measured position from some prominent feature of the model, preferably a face at right angles to the longitudinal centre line, so that at a later inspection it is possible to obtain the same exact positions by a similar measurement from the same feature. The spanwise chord locations remain as indicated on the drawing. Measurements are taken at regular intervals from the master datum along the chord, thus forming the grid pattern in plan. The dimensions of upper and lower surfaces are then recorded at these points (Fig. 2).

Use of this technique completely eliminates the possibility of errors in locating the correct position to commence thickness readings along the chord. Errors in sweep-back angle are therefore not related

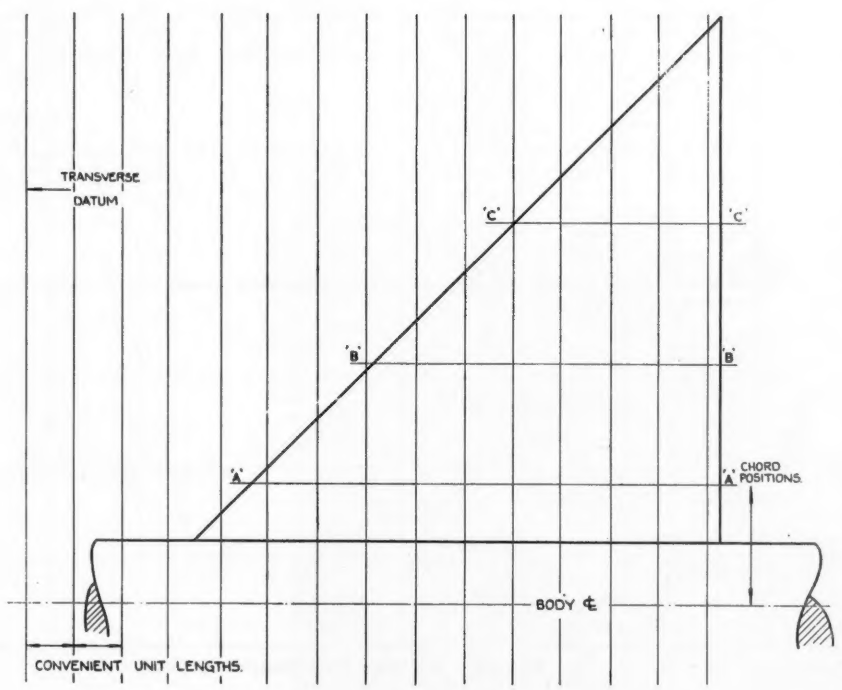


Fig. 1. Grid formation for dimension plotting

POSITION FROM TRANSVERSE DATUM	CHORD 'A'-'A'		CHORD 'B'-'B'		CHORD 'C'-'C'	
	'U'	'L'	'U'	'L'	'U'	'L'
0						
1						
2						
3	0·234	0·265				
4	0·314	0·346				
5	0·385	0·408	0·165	0·203		
6	0·425	0·457	0·250	0·283		
7	0·466	0·499	0·305	0·337	0·204	0·220
8	0·502	0·536	0·354	0·385	0·260	0·273
9	0·535	0·566	0·383	0·414	0·306	0·320
10	0·563	0·593	0·422	0·454	0·339	0·355
11	0·590	0·615	0·451	0·477	0·368	0·383
12	0·610	0·636	0·478	0·496	0·391	0·406

'U'- THICKNESS ABOVE ℄. 'L' - THICKNESS BELOW ℄.

Fig. 2. Example of presentation of the figures

to thicknesses at given chord positions. The information recorded can be used in two ways. Either a large scale graph can be drawn to show errors both in the position and thickness of section, together with correctness of chord and inclination to the body centre line (Fig. 3) and the true section can be drawn and accurately positioned upon this graph which provides a check on the leading edge straightness. Alternatively, thicknesses at the new positions along the chord can be calculated.

A major problem is the complete assessment of the leading edge formation, and to a lesser degree, the trailing edge. Various methods have been used, many of them of a mechanical nature and requiring the use of some form of stylus moving around the leading edge in order to obtain the contour.

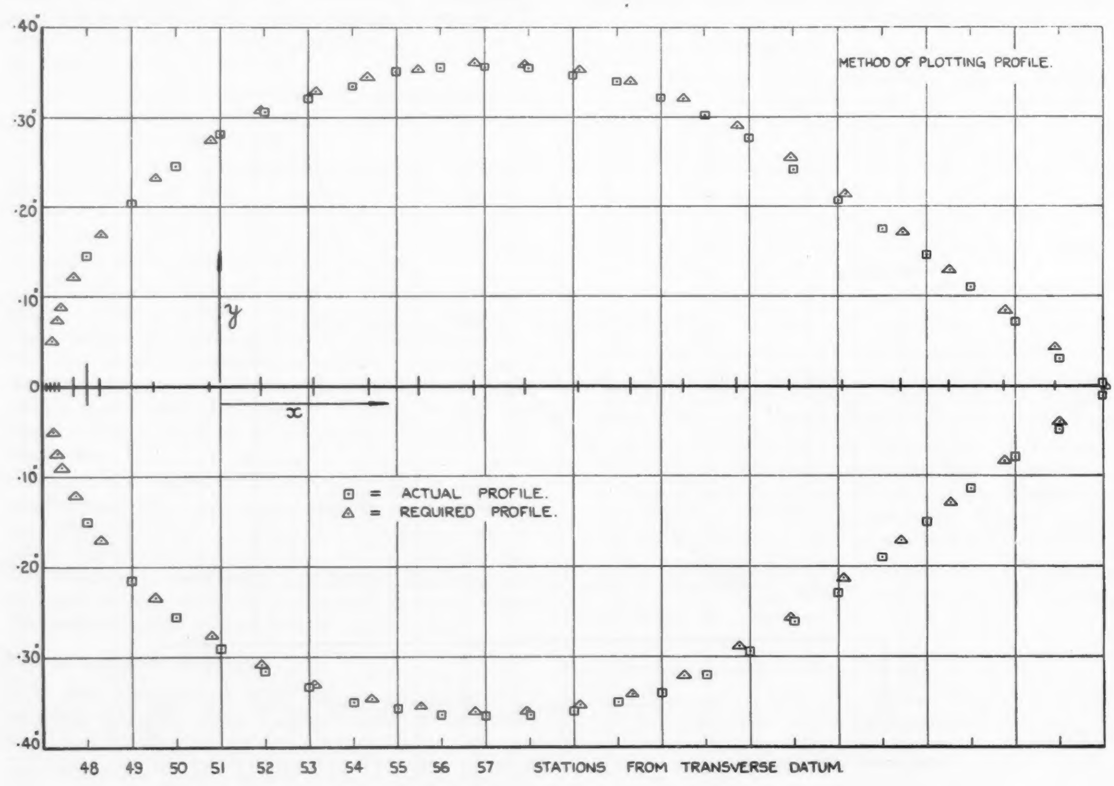


Fig. 3. Graph showing actual and true profiles

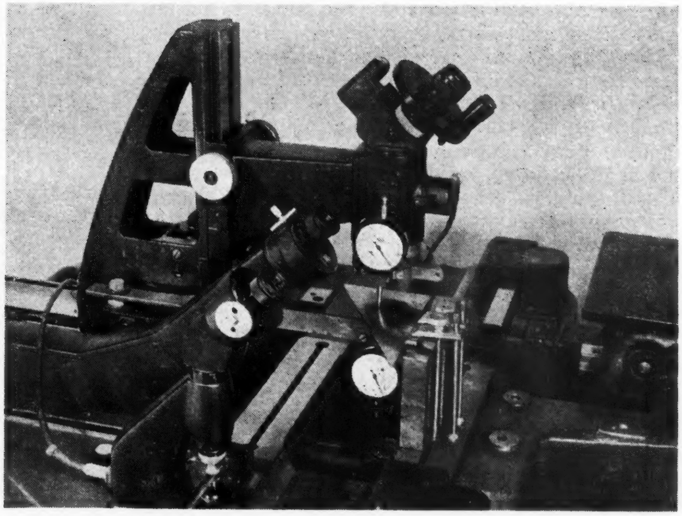


Fig. 4.
The Zeiss Universal Measuring Microscope

Until recently, it was believed that no mechanical system would give the complete answer and an optical scheme was developed to discard all mechanical contact.

The technical requirements are such that a picture of the actual formation of the leading edge is preferable to a series of spaced readings; this has been made possible by using optical and light reflective methods.

A similar grid technique is employed for measuring body profiles. It is often necessary, however, when measuring body profiles of nearly circular section, to use a contact probe with an electrical indicating device, in conjunction with dial indicators and slip gauges, to take dimensions of a complete upper surface in one setting of the model.

types of equipment

There is a limited range of suitable equipment on the open market for the positioning of the grid pattern on the smaller models, viz., the Zeiss Universal Measuring Microscope and the Société Genevoise M.U.214B.

The Zeiss machine (Fig. 4) has a measuring capacity in plan form of 200 mm. (approximately 8 in.) by 100 mm. with a basic scale accuracy of 1 micron, but has no provision for obtaining the third dimension, and the machine has to be specially rigged to carry two vertically opposed dial gauges reading the measure chordal thicknesses.

These dial indicators are frequently checked for accuracy of calibration over their complete range. Those used to measure the small models are graduated in 0.0001 in. Their contact pressure, of the order of 25 gram, is, however, a serious issue with thin wings and particularly along the trailing edge section. Experiments have been made with indicators having a contact pressure of $2\frac{1}{2}$ gram, but it appears this is still too much for very thin sections and experiments

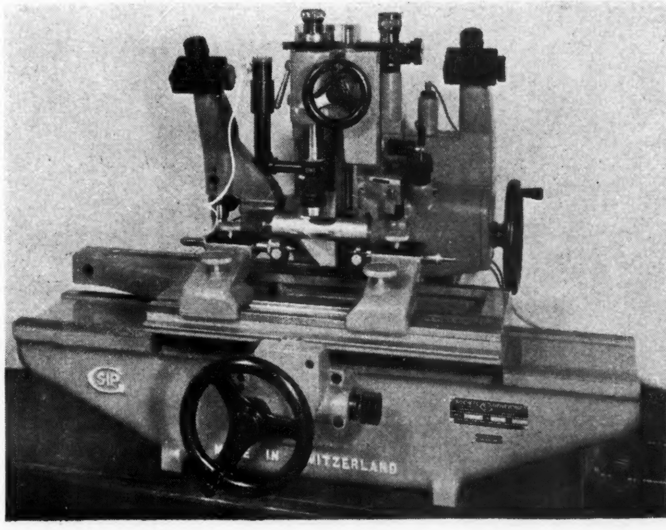


Fig. 5.
The Société Genevoise M.U. 214B

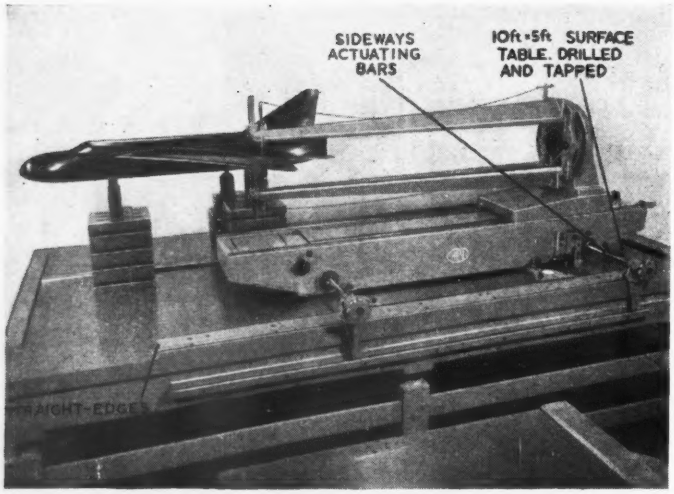


Fig. 6. Royal Aircraft Establishment caliper machine

Fig. 7. Royal Aircraft Establishment caliper machine

show that a pressure as low as 1 gram must be employed for consistent accuracy to the order of 0.0001 in.

The Société Genevoise machine (Fig. 5) has a slightly larger measuring capacity of 16 in. × 4 in. with a basic scale accuracy of 0.00005 in. and also a vertical head with a measuring range of 4 in., using a short-focus measuring microscope.

With some experience in using this microscope, it is possible to develop an ability to repeat readings to 0.001 in., but continual use results in severe eye strain. The short-focus microscope must, in the writer's opinion, be regarded as an interim measure.

There is another machine with a slightly larger capacity, developed by Société Genevoise primarily for measuring large pipe threads, and which, when suitably modified, can be adapted to the inspection of aircraft models. It will have a measuring capacity of 33½ in. × 12 in. × 6⅝ in. This machine, with its modifications, is now in use at the Royal Aircraft Establishment.

Apart from these machines, to the writer's knowledge there is none other available for accurately measuring the larger models and the metrologist must either adapt a jig borer, which becomes an expensive inspection machine and slow in operation, for the purpose or alternatively construct a special inspection machine. The Royal Aircraft Establishment employ both means for overcoming the problem and among the special machines which have been designed by the Establishment are:

the caliper machine

The model (Figs. 6 and 7) is set up in the horizontal plane on this machine, with its trailing edge parallel to the surface table and its axes square to straight edges, optically positioned on the table.

The grid pattern is obtained by longitudinal and transverse settings of the carriage, relative to the straight edges by using setting blocks and fiducial indicators, the caliper arms thereby traversing the model. The dial indicators are set to zero by measuring the maximum thickness of the wing and setting the top and bottom indicators to the mid-position.

This type of measuring machine has now been employed by the Royal Aircraft Establishment for several years and during this period has been made progressively more robust and more accurate to meet the increasing demands of the aerodynamicist for accuracy, but of course, the limiting accuracy of such a machine is set by the need to employ dial indicators of a reach as much as 2 in. It can be fairly stated, however, that measurements are accurate to the order of 0.0005 in. and in any case to less than 0.001 in. on wings up to 4 ft. span; in fact the degree of accuracy is not much less on wings up to 8 ft. span.

The measuring machine itself is mounted on a 10 ft. × 5 ft. grade "A" surface table. The table top is drilled and tapped at 6 in. spacing in a grid formation to facilitate the mounting of models. The machine can be positioned anywhere on the table and is provided with a retractable undercarriage to facilitate such movement. Exact positioning of the machine is effected by quick action actuating bars.

The carriage has a traverse along special guide-ways of 56 in. and both coarse and fine movements are provided. Its final position is set by end-bars.

Each of the two caliper arms has a reach of 57 in.; the pair can be rotated through 360° and the gap between them can be varied. To avoid damaging the surface of the model during movement of the carriage, the points of the indicators are lifted clear after each ordinate reading by means of cords attached to the indicator sleeves.

As will be seen in Fig. 7, provision is made to fit a camera to photograph the readings of the dial indicators.

co-ordinate table

This table (Fig. 8) was devised by the Royal Aircraft Establishment and has a measuring capacity in plan form of 33 in. × 20 in. It was originally intended

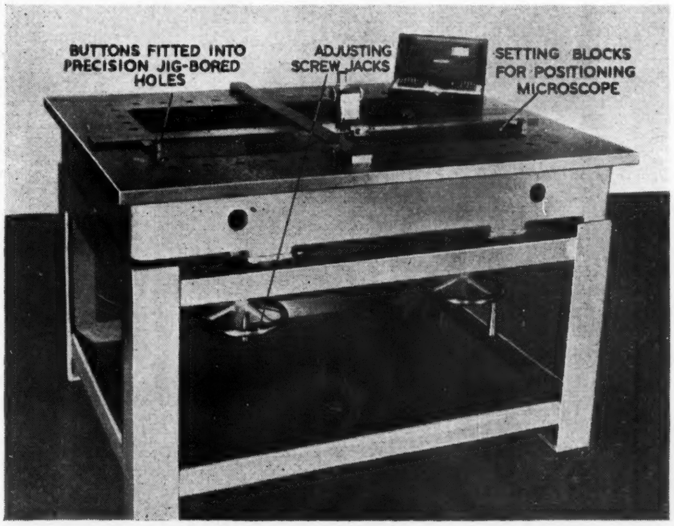


Fig. 8. Co-ordinate table

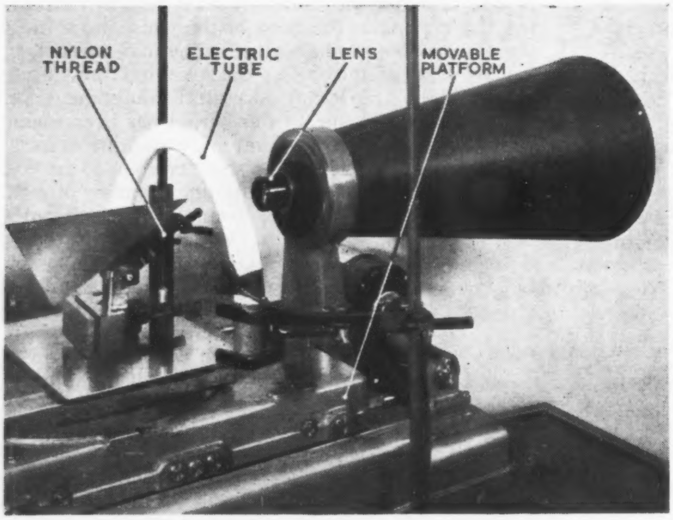


Fig. 9. General assembly of "nylon thread" equipment

for the accurate measurement of large aerofoil templates, and for tunnel models needing accurate plan form dimensions. Facilities for a third dimensional measuring plane were subsequently added. Up to the present, these vertical dimensions are obtained by means of a short-focus measuring microscope.

This equipment comprises two tables, one within the other, the outer being fixed to the floor and the inner table having a vertical movement of $4\frac{1}{2}$ in., its height being adjustable by three screw-jacks. Three machined pads on the under surface of the outer table, immediately over the jacking stations, enable the inner table to be set parallel to the outer table by inserting setting blocks.

The opening in the outer table is spanned by two straight-edges, at right angles to each other, for making co-ordinate measurements, these being positioned to buttons fitted into precision jig-bored holes accurately spaced at 3 in. pitch along each edge of the opening. The holes are so positioned that the straight-edges conform to a regular grid pattern and, additionally, sweep-back angles can be determined by using the arrangement of buttons and straight-edge as a sine-bar.

The microscope carriage which travels along one of the straight-edges is positioned accurately at stations between buttons by using setting blocks.

A weakness in the present arrangement is the possibility of deflection of the straight-edges, and improvements are under consideration to increase the vertical section of these members. Another development is to replace one of the straight edges with a "line" scale to make positioning of the microscope more accurate. Nevertheless, repeatability on this machine is within 0.0005 in.

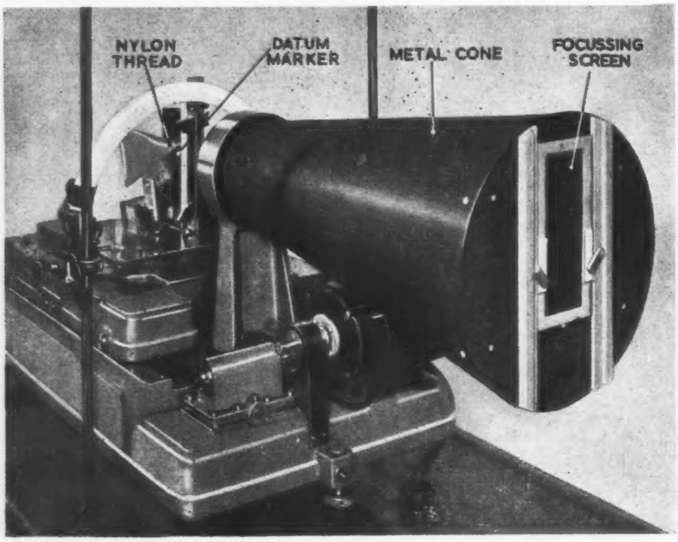


Fig. 10. Datum marker and focussing screen

measurement of the leading edge

The accurate measurement of the leading and trailing edges presents a most difficult metrology problem, and several methods have been used at different times. Most of these have been of a mechanical nature and have required the use of some form of contact stylus moving around the aerofoil.

mechanical method

One of the most successful mechanical methods used a pantograph, the construction of which involved the base and upright of a Chesterman height gauge, having two adjustable heads, one of which carried the follower and the other the scribing point. The model under examination was held vertically and with the apparatus set at a magnification of one to one the follower traced around the required section, whilst the scribing point was simultaneously in contact with a smoked glass plate. This method was successful for general profiling, but the inability to maintain constant pressure on the follower, due to the human element, led to difficulty being experienced when tracing the leading edge. This method was therefore restricted to radii in excess of 0.025 in. From these results it was obvious that some device which would eliminate the human touch was therefore necessary.

nylon thread method

However, it was believed that no mechanical contact method would give the complete answer and a system was developed which completely discarded the stylus or follower. The technical requirements of inspection are such that it is desirable to view the entire contour of the section under examination and this has been made possible by using an optical and light reflective system.

Here a technique has been developed using a simple lens system, viewing screen and photographic plates. The model, attached to a platform movable fore and aft for focussing, has its leading edge held in a horizontal plane. A lens of suitable focal length is mounted vertically, immediately in front of the wing and in line with the leading edge. The lens is located in a metal cone, which also holds a ground glass focussing screen, and is positioned to give the desired magnification (Fig. 9 and Fig. 10).

A fine thread draped over the leading edge profile and held taut by means of a small weight, is illuminated by a semi-circular electric light tube placed between the lens and the thread. By means of the travelling platform the thread can be focussed from any position along the leading edge on to the screen. When the position under examination has been brought into focus, a photographic slide-holder replaces the glass screen and a permanent record is

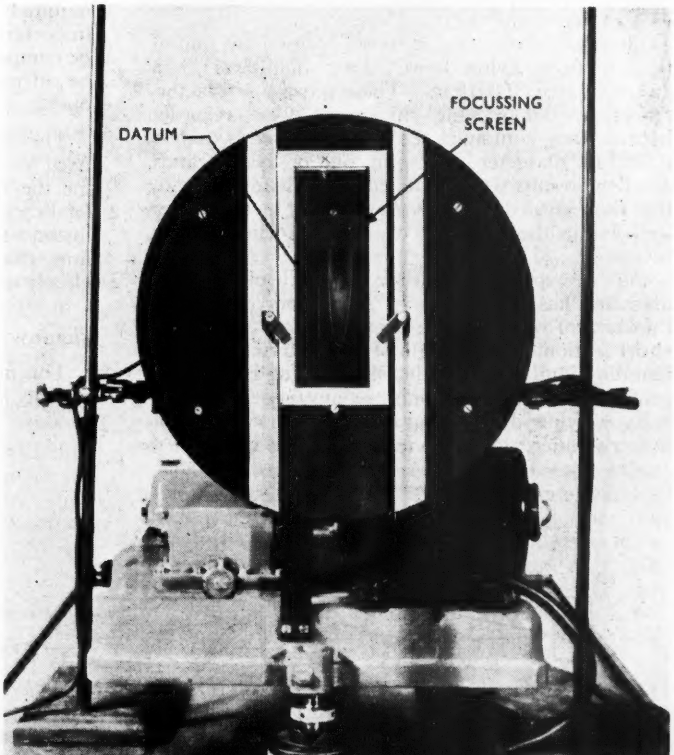


Fig. 11. Image and datum

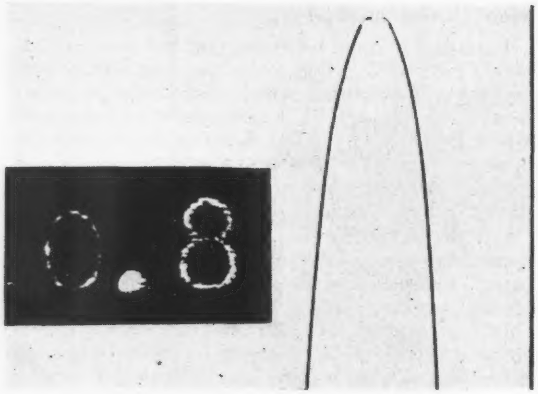


Fig. 12. Recorded profile

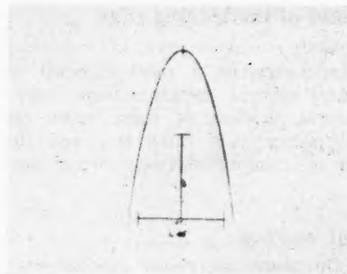


Fig. 13. Master profile graticule

obtained (Fig. 11). On this record of the aerofoil is included a known datum width, for use in accurately viewing the plate at a definite magnification during subsequent measurement (Figs. 12 and 13).

Experiments with this equipment show the importance of thread diameter and material. Platinum wire of 0.001 in. diameter, first chosen because of its reflecting quality and fineness, gave fairly good results. It was found, however, that the weight required to straighten any " kink " in the wire exceeded the breaking load.

The next choice, nylon, was obtained by pulling threads from nylon fabric, their diameters being approximately 0.0015 in. These gave a satisfactory reflection, but varying thicknesses were recorded because they contained ten separate strands each of 0.0003 in. diameter. By using one of these strands, excellent results were obtained, the advantage being that the recorded profile was enveloped by a thickness well within the tolerance of manufacturing requirements.

Further experiments with nylon bristle of 0.0015 in. diameter has given a very satisfactory result, the thickness of reflected line being uniform around the entire section. The strength of this material facilitates handling, and a slightly heavier loading enables the profile to be determined more accurately.

By viewing the photographic plates with a toolmaker's microscope having a direct reading to 0.00004 in. (0.001 mm.) and bearing in mind that these plates have an initial magnification, readings are obtainable to better than 0.0001 in.

This method has proved satisfactory for most inspectional requirements, and has led to a further development. With the system introduced into the workshops, the form of the leading edge and wing profile can be readily checked by viewing upon the ground glass screen. If the apparatus used is set at a nominal magnification, photographic graticules of important profiles of any position along the wing can be compared with the actual profile. Adjustment can be effected to the wing at this stage, enabling the operator to work within very fine limits.

The shortcomings of this method are, firstly, the need for dark-room operation, secondly, the tendency for the draped thread to slide down a swept-back leading edge if chordwise shape is to be obtained as distinct from a section normal to the leading edge, and, thirdly, the inability of the thread to follow closely any depression in the profile.

shadow projection method

This method uses an entirely optical approach and consists simply of a photographic record taken of a shadow cast over the wing at a predetermined position.

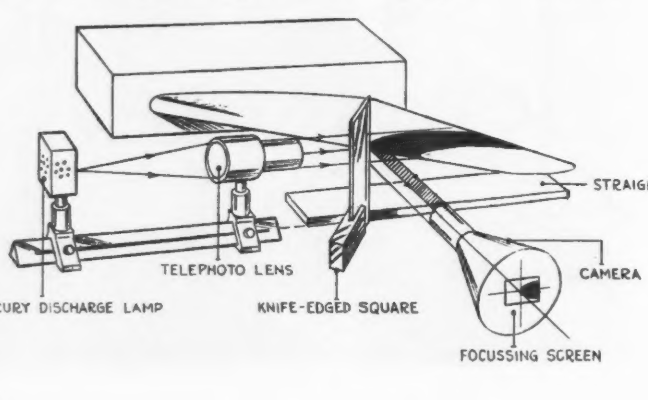


Fig. 14. Diagrammatic set-up of the " shadowgraph " for leading edge measurements

A collimated beam of light is directed on to the leading edge in the direction of airflow and a cut-off is interposed to cause a shadow to fall across the aerofoil to produce a true section of the required leading edge profile (Fig. 14).

This shadow is then viewed from a position at right angles to the line of airflow by means of a focussing screen and lens capable of being adjusted to give a range of magnifications. When the image of the shadow has been sharply focussed on to the frosted glass screen, the screen is removed and a photographic plate inserted and exposed. This record of the profile can then be measured by means of a toolmaker's microscope or projector.

To emphasise the intensity of the shadow and to provide maximum contrast between its edge and the illuminated surface of the wing, the positions at which the leading edge profiles are to be photographed should be sprayed with a solution of $4\frac{1}{2}\%$ acenapthene and 50/50 acetone and petroleum ether (this solution does not add any appreciable amount to the wing thickness).

The chief advantages of this method are:—

(a) depressions can readily be seen (Fig. 15),

(b) this method may be used if the wing is supported vertically,

(c) a series of lenses is not required for a model having a large span, as is the case with the " nylon bristle " method.

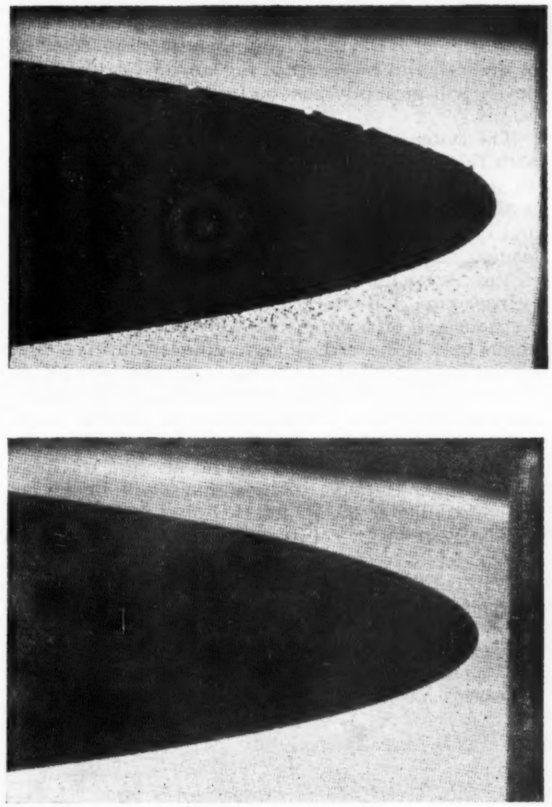


Fig. 15. Section of leading edge produced by "Shadowgraph" method

measurement of waviness

A method of satisfactorily measuring the waviness is to take readings spaced at 0.1 in. over the complete aerofoil, from which the waviness errors may be calculated. On a " Delta " half-wing of 10 in. × 10 in. this necessitates taking approximately 5,000 readings.

Practical considerations of time and labour with present facilities, however, usually limits the number of readings to approximately 2,000 and it is realised that there is often doubt as to the actual contour between grid points.

There is an urgent need, therefore, for a measuring machine capable not only of measuring to a high degree of accuracy, but also with a speed of operation far beyond the capability of any metrologist. Thus, the machine must be automatic in action. Without such a means of speedily dimensioning each model, it will be impossible in the time available to meet the aerodynamicist's full requirement of measuring surface waviness.

three-dimensional automatic model measuring machine

general description

On behalf of the Royal Aircraft Establishment, the writer's reaction to the special problems posed by the detailed analysis requirement of these models has been to initiate the development of a programme controlled inspection machine (Fig. 16).

Here again the grid pattern technique is employed, but with the added advantage that the size of the resulting mesh can be considerably reduced. In fact it is hoped so to close the grid as to obtain an effective check of waviness. The greater number of readings is rendered feasible by a measure of automation.

This machine will consist basically of a carriage which can be traversed horizontally between two gauging heads. Each of these heads will be adjustable vertically up guide pillars, and will include a stylus which can be moved towards and away from the other head. Digital scales will be provided on each of the four linear motions; and a control unit will enable the horizontal movement of the carriage and the vertical movements of the heads to be preset and the horizontal displacements of the styli to be recorded.

In use, the model to be inspected will be mounted on the carriage with its longitudinal axis horizontal and its spanwise axis vertical—to minimise distortion. The grid points at which inspection is desired will be defined on punched cards and will be read in pairs to specify successive positions for the carriage and the

gauging heads. As soon as these positions have been reached, each gauging stylus will be moved inwards until it touches the model and then the displacements of the styli will be recorded on punched cards. The device will promptly pass on to the next pair of grid points.

The system as described will, of course, only deal with those surfaces of the models which are, say, at an angle of not more than 45° to the axis of the inspecting styli. But minor complication of the styli and of the inspecting sequence will enable even the leading edges of highly swept wings to be inspected in this automatic manner.

Inspection will proceed at about 300 grid points per hour and on large models as many as 30,000 grid points may be needed. The resulting data cards will be fed into the fast electronic calculator DEUCE, which will assess the data so recorded and will punch out summary cards. From these cards, contour maps will be printed, to show the discrepancies between the actual and the required forms and also the waviness of the whole surface. These maps will be in an easily assimilable form and will be passed to the aerodynamicists for comment on the acceptability of the model.

Needless to say, such inspection will be far more complete than any that can be attempted under present conditions ot purely manual operation of somewhat similar devices.

Note that although this machine is not a cutting tool, it does fall within the broad class of preset-and-cut machines. At each stage the positions of the carriage and gauging heads are preset, and then the equivalent of a cut is taken by moving the gauging styli forward until they touch the workpiece and initiate recording. Note too that such a machine forms a useful starting point for an automation programme, as many difficulties associated with machine tools—such as vibration—are absent.

fundamental design requirements

The base casting, upon which is mounted the main horizontal guideway, must have ample depth of section giving extreme rigidity, and be supported at three points, two of which should be adjustable for height. To a carriage which can be moved along accurate horizontal ways is fixed the model to be inspected—with its spanwise (Y) axis vertical and its longitudinal (X) axis parallel to the ways. On each side of those ways is a pair of vertical pillars, up which can be moved a support for a gauging head. Each of these heads can be traversed automatically along a horizontal axis (Z) perpendicular to (X), until

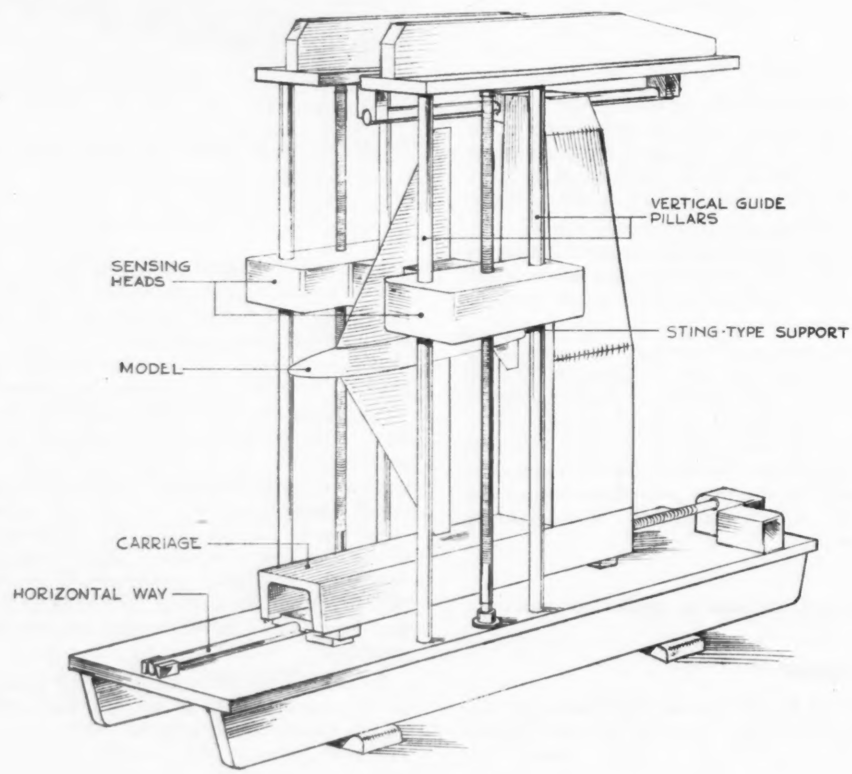


Fig. 16. Three-dimensional aerofoil inspection machine

deflection of a sensitive stylus indicates that the head is at a known distance from the surface of the model. The heads can thus detect the displacement of much of the model's surface from a datum plane at each of many grid points by positioning the heads vertically and the carriage horizontally.

The leading edge of the wing cannot always be inspected in this way, and to enable this to be done provision is made for swinging one or other of the sensing styli from its normal position—with its sensitive axis parallel to the Z axis of the model—to a special position with the sensitive axis in the XY plane. The arrangement employed will differ slightly on the two sensing heads. In one case the special position of the sensitive axis will be parallel to the X axis and will be obtained by swinging the stylus guide about a horizontal axis at 45° to the Z axis and passing through the null position of the tip of the stylus. This stylus is used to inspect the leading edge of slightly swept wings—by moving it to each of a number of stations across the leading edge by means of its Z lead screw and then advancing the model carriage until the stylus makes contact with the leading edge.

In the case of models with highly swept wings, this arrangement would result in the stylus striking the wing very obliquely and to overcome this the second of the two sensing heads is provided with a slightly different method of swinging the stylus. The angle between the sensitive axis of the stylus and the axis about which it swings is increased to about 55°, so that the sensitive axis can take up two positions in the XY plane inclined at $\pm 45°$ to the X axis.

In the few cases where the angle of sweep-back is almost 90°, the leading edge is again inspected by the second of the two sensing heads, but in this case the X and Z co-ordinates are preset and the Y co-ordinate driven till the stylus makes contact. In the case of models whose leading edges have to be inspected in this way, it is convenient to inspect the remainder of the model by a series of readings taken along lines parallel to the Y axis.

Of these three methods of operation, the desired method will be selected manually by means of a switch on the control panel.

The five motions are obtained from nuts working on accurate lead screws—the two screws controlling the vertical movement of the gauging heads being mechanically coupled to ensure that any forces the heads impose on the model are directly opposed, thus minimising distortion, particularly of thin aerofoils. Four servo motors suffice to control the device and the positions of the various components are indicated by four multi-turn shaft digitisers coupled to the lead screws.

capacity and accuracy

The horizontal traverse of the carriage and the vertical traverse of the gauging heads is to be 52 in. The horizontal ranges of both gauging heads is to be 5 in. and these ranges will overlap by 2 in. The grid points will be defined (mesh size of the inspection grid is not likely to exceed $\frac{1}{4}$ in. $\times$ $\frac{1}{2}$ in. in the axial and spanwise directions respectively) and the departure of each surface from datum at those points must be measured and recorded to the following tolerances:

In any square 1 in. × 1 in.	...	± 0.00005 in.
Over 1 in. × 1 in. and up to 4 in. × 4 in.	...	± 0.00010 in.
Over 4 in. × 4 in. and up to 20 in. × 20 in.	...	± 0.00025 in.
Over 20 in. × 20 in. and up to 52 in. × 52 in.	...	± 0.00050 in.

The accuracy to which the main carriage and measuring head will be positioned in relation to grid pattern:

1 in.	... ...	0.0001 in.
4 in.	... ...	0.0002 in.
10 in.	... ...	0.0003 in.
20 in.	... ...	0.0004 in.
52 in.	... ...	0.0005 in.

conclusions

There is an urgent need to make models more quickly and more accurately and also to measure them more completely and in a much shorter space of time.

Much thought has been given during the past few years to the problem of producing complicated high-speed wind tunnel models in a much shorter floor to floor cycle time, and the Paper titled " Automation in a Research and Development Workshop " (iii) given by the writer as principal author, assisted by Messrs. S. W. Potter and E. J. Petherick, to the Southern Branch of the Institution of Mechanical Engineers at Farnborough on 20th, March 1956, covers most comprehensively the way in which this problem is being tackled.

This Thesis has attempted to indicate that the metrology of such models can indeed be more troublesome than the manufacturing problem and consequently cause just as severe bottlenecks.

Further, it has been indicated that the human element must be replaced as far as possible in this work and therefore automatic means of measuring is the logical course to pursue.

bibliography

No.	*Author*	*Title, etc.*
(i)	—	Royal Aircraft Establishment Technical Memo. No.: Aero 460. Accuracy and finish required of Wind Tunnel Models.
(ii)	H. T. Hill	Royal Aircraft Establishment Technical Note No.: A.D.W.1. Inspection Techniques Applied to the Metrology of Aerodynamic Models.
(iii)	H. T. Hill S. W. Potter E. J. Petherick	Royal Aircraft Establishment Technical Memo: No.: A.D.W. 3. Automation in a Research and Development Workshop. (Presented to the Institute of Mechanical Engineers—Southern Branch—at Farnborough on 20th, March 1956.

Production Engineering Research Association of Great Britain

Quarterly Newsletter to the Institution

HIS Royal Highness the Duke of Edinburgh recently paid a special visit to the Production Engineering Research Association, arriving in Melton Mowbray by train and leaving PERA grounds by helicopter at the end of his visit. Prince Philip expressed keen interest in PERA early in 1958 and indicated at that time that he would like to study for himself the ways in which PERA is helping member firms to improve production efficiency.

His Royal Highness was met on arrival by Dr. D. F. Galloway, Director of PERA, who presented representatives of the Town and district. The Duke was met at the Association's Headquarters by Sir William Stanier, the President, and Sir Lionel Kearns, Chairman of Council. His Royal Highness was then taken on a tour of the workshops and laboratories which lasted about two hours.

The tour began in the entrance hall of the new research block where a special display of information services and of some of the products made by members had been arranged. The Duke expressed surprise at the great variety of these products, which now range from nuclear reactors and guided missiles to toys and nylon stockings. At this point, the Duke was also introduced to members of the staff concerned with translation of Russian literature.

H.R.H. The Duke of Edinburgh placing a billet in a die mounted in PERA's 1,000-ton cold extrusion press. The Duke then operated the press to produce a 5 ft. fuel canister for a nuclear reactor

Prince Philip then entered the main workshops and toured the metal cutting, metal forming, vibration and electronics sections. Many members of the staff were introduced to the Duke, who throughout the visit displayed a very lively interest in all aspects of the Association's work. He also revealed a firm grasp of the problems of the production engineer and readily appreciated the economic and practical significance of the investigations in progress.

In his tour of the automation section, the Duke was particularly impressed by a numerically controlled machine tool which had been programmed to machine the name 'Philip' in script characters in an aluminium plate.

The PERA Film Unit was filming drill grinding activities during the tour and Prince Philip took part in an instructional sequence that was being filmed. Other metal cutting activities which he found especially interesting were the experiments being carried out in the radioactive laboratory with activated cemented carbide tools, and the milling of high tensile steels.

After a short break, the tour of the laboratories was continued at the metal forming section. Here the Duke placed a slug in the large extrusion press and operated the press himself to produce a 5 ft. long extrusion. As this was a forward extrusion operation in which extrusion took place within the body of the die, the camera in a closed television circuit was placed beneath the die to show the component actually being extruded. The mechanism of cold extrusion was also diagrammatically explained in a short colour film. Prince Philip also took a keen interest in various other developments in the metal forming section, including finish blanking, finish piercing, deep drawing, and barrelling.

Following a tour of the machine tool, metrology, chemical and metallurgical laboratories, various aspects of the work of the Technical Enquiry Section were discussed. The Duke was particularly impressed by the substantial savings made by member-firms which have used the Section's facilities for designing special purpose production equipment, carrying out efficiency surveys, investigating factory layout, and studying methods and handling in particular factories.

Prince Philip then visited the mobile demonstration unit where he heard part of a lecture by a liaison engineer and saw various scenes from PERA films. Finally, Prince Philip visited the Photographic and Filming Section and the Education and Training Department.

REPORT OF THE MEETING OF COUNCIL

29th January, 1959

THE third Council Meeting of the 1958/59 Session was held on Thursday, 29th January, 1959, at the Headquarters of the Institution, 10, Chesterfield Street, Mayfair, London, W.1, at 11 a.m. The Chairman of Council, Mr. H. W. Bowen, O.B.E., presided over the meeting, which was attended by 28 Members. Also present, by invitation, were Mr. B. Brewster, Chairman of the Coventry Graduate Section; Mr. P. J. Shipton, Chairman of the Wolverhampton Section; and Mr. C. Ll. Griffiths, Hon. Secretary of the Cardiff Section.

Election of President, 1959/60

It was recommended by the Finance & General Purposes Committee, and unanimously approved, that Mr. G. Ronald Pryor be nominated President of the Institution for the year commencing 1st July, 1959.

Election of Vice-President, 1959/60

It was the recommendation of the Finance & General Purposes Committee that Mr. J. E. Hill be nominated a Vice-President of the Institution for the year commencing 1st July, 1959, but Mr. Hill, addressing the Council, said that although he was indeed conscious of this honour, during the last six months he had taken on additional industrial responsibilities which precluded him accepting such an office.

He did, however, wish to propose the name of a man who had done a very great deal for the Institution, that of Mr. Harold Burke. Mr. G. R. Pryor seconded Mr. Hill's proposition, which was carried unanimously.

Annual Subscriptions

It was recommended by the Finance & General Purposes Committee that because the present margin of excess of income over expenditure was inadequate to meet the Institution's needs and provide for future progress, the annual subscription rates for the various grades of membership should be increased as follows:

	Proposed New Rate	*Present Rate in U.K.*
Members	8 8 0	*6 6 0*
Associate Members	6 6 0	*5 5 0*
Associates	6 6 0	*5 5 0*
Graduates (30 years of age and over)	4 4 0	*3 13 6*
Graduates (under the age of 30 years)	3 13 6	
Students	2 2 0	*2 0 0*
Life Membership	84 0 0	*63 0 0*

Entrance fees. Entrance fees (where payable) shall equal one year's subscription for the grade to which applicant is elected.

NOTE—(i) No increase is recommended for Affiliated Organisations.

(ii) For members outside the U.K. the present membership subscription is 10s. 6d. less for each grade of membership. The Vice-Chairman of Council is corresponding on this point with officers outside the United Kingdom.

The recommendation was adopted and will be submitted to an Extraordinary General Meeting of the Membership.

Membership Subscriptions under Deed of Covenant

In view of the provisions made under Section 16, Finance Act, 1959, the Finance & General Purposes Committee had agreed to make no further claims to Inland Revenue for refund of tax on membership subscriptions covenants as from April, 1958.

South African Council

The Council were pleased to receive from the South African Council the sum of £400 to cover the current year's *per capital* levy, the balance being a contribution towards the Institution as a whole.

Secretary's Visit to Australia

It was reported that the Australian Council had proposed that the Secretary of the Institution, Mr. W. F. S. Woodford, should visit Australia for a period of four to five weeks during February and March, 1960. The Council adopted the Finance & General Purposes Committee's recommendation that

the proposal by the Australian Council be agreed in principle, and agreed to examine also the possibility of the Secretary visiting other overseas Sections at the same time.

Immediate Past Chairman of Council

It was pointed out by the Finance & General Purposes Committee that the Institution's present constitution did not provide for the best use being made of the services of the immediate Past Chairman of Council, which would be of immense value due to the experience gained during his period of office. It was agreed, therefore, that the Articles of Association be amended so that in future the immediate Past Chairman of Council be included among the Principal Officers.

The Journal

It was reported by the Editorial Committee that discussions were taking place on future Journal policy, with particular reference to the presentation of editorial matter. Various suggestions had been made regarding the introduction of new features, and these and other relevant matters would be considered in detail over the next few months.

Close collaboration was being maintained between the Editorial and Papers Committees in exploiting various sources for obtaining publishable material for the Journal, and discussions on this subject have taken place between Chairmen of all Standing Committees with a view to obtaining some useful suggestions.

The advertising situation continues to be reasonably satisfactory and during the period under review several new advertisers have taken space in the Journal. The Chairman of the Committee continues to keep in close touch with the Advertising Agents in this respect, but Council Members were again urged to give the maximum support to the Journal.

Institution Papers

The Papers Committee reported that the 1958 Sir Alfred Herbert Paper, presented at the Royal Institution in December by Sir Cecil Weir, was very well attended and received wide publicity. The subject was "The European Common Market, The Free Trade Area, and The Production Engineer" A report of the meeting, with the Paper, appeared in the February Journal.

The 1959 George Bray Memorial Lecture will be presented early in 1960, on the subject of packaging of engineering products for transit and storage at home and overseas. The speaker will be Mr. C. H. Bulmer, of The Printing, Packaging and Allied Trades Association.

Arrangements had also been made for the presentation of The 1959 Viscount Nuffield and E. W. Hancock Papers, the former being given in Glasgow by Dr. Timms, of M.E.R.L., and the latter in Bristol by Mr. R. A. Banks, Personal Director of I.C.I. Ltd. Details of these meetings would as usual be circulated to members well in advance.

The Chairman of the Papers Committee, Mr. F. C. Cooke, has been invited to serve on the Awards Sub-Committee.

Research

The following reports were made on behalf of the Research Committee:

Materials Handling The new Chairman of the Group is Mr. F. E. Rattlidge. Discussions are continuing with representatives from the Building Research Station on the co-operation necessary, in building a factory, between the architect and the production engineer.

Control of Quality The Sub-Committee has been reconstituted, with revised terms of reference, to consider further activities following the success of the Report on "Quality — Its Creation and Control", and is now engaged in planning a Conference to be held during the coming summer.

Co-ordination of Production Management Techniques This Study Group has now been formed into a Sub-Committee and is in the process of drafting its Report.

Computers and Production Control This Sub-Committee has been formed from the Study Group on "Electronics and Kindred Modern Developments as applied to Process Loading," and a Report is being drafted.

Standardisation

It was reported by the Standards Committee that the Sub-Committee on International Standards was now engaged on reading and preparing comments on the implementation of International Recommendations for submission to the Main Committee, and was also investigating the effect of standards and standardisation in the Common Market and Free Trade Area.

The Sub-Committee on Unit Heads and Platens was being recalled to formulate proposals for the standardisation of limit switches as used on machine tools.

There had also been a meeting, during the quarter, of the Joint I.Prod.E./B.S.I. Standing Advisory Committee on the use of Standards in Industry, one of the main items of discussion being the drafting of a Code of Practice for setting up a Standards Department. The formation of a Standards Society was still under consideration.

Membership

The Council approved a number of applications for election and transfer, details of which appear on pages 157 - 158.

Region and Section Quarterly Reports

The Council received a number of Region and Section Quarterly Reports.

Honours

It gave the Council much pleasure to record the names of several members who had been honoured

by Her Majesty the Queen, details of which appear on page 161 of this Journal.

Obituary

The Council were sorry to learn of the deaths of the following members:

Associate Members

G. Whyatt; J. W. Challenor; T. B. Whitehouse; W. Bellamy, J. W. Butcher; J. G. Buck.

Associate

A. R. Chapman.

Date and Place of Next Meeting

It was agreed that the next meeting of the Council should take place on 30th April, 1959, at 11 a.m., at 10, Chesterfield Street, Mayfair, London, W.1, and that an Extraordinary General Meeting be convened for the same day.

ELECTIONS AND TRANSFERS

20th January, 1959

BIRMINGHAM SECTION

As Associate Members
D. H. R. Shaw; L. R. Brazier, H. D. Kettle; R. E. Hanley; P. J. Villers.
As Graduates
D. J. Stonehouse; M. V. Nichol; G. S. Essex; R. A. Yardley; P. Barrington; A. Taylor; S. Taylor; C. G. Salmon; M. L. Bird; M. B. Pakes; J. E. Allsopp; R. Cockin; R. V. W. Forsyth; G. Mitchell; D. Fletcher; G. M. Coggan.
As Students
S. C. Saluja; R. H. Tuppeny; E. G. Salt; C. P. C. Jones; J. E. Henson; J. G. Lacey; R. A. Kendall; M. J. Morrissey; B. Allen; J. F. Aston; R. L. W. Holder; J. G. Laing; J. E. Whorwood; K. J. Gray; A. F. Murcott.
Transfers
From Associate Members to Members
G. J. Gough; F. C. Shelley.
From Graduates to Associate Members
J. L. Hughes; A. S. Brett; P. G. Atkins; L. H. W. Harris; H. Moore; L. J. Ward; P. Binks.
From Students to Graduates
P. A. Byrne; D. C. Newton; R. A. Irons; P. C. Higgins; N. J. Christmas.

BOMBAY SECTION

As Graduates
K. N. Ramanarayanan; N. H. Shah.
As Students
D. K. Bhattacharya; C. P. Narang; A. K. Banerjee; C. P. Srivastava; K. Jayaswal; H. S. Matharu; M. E. Naidu; S. S. Sachdev; I. N. Jayaswal.
New Affiliated Firm
Messrs. Champion Engineering Works Ltd.
Transfer
From Student to Graduate
V. V. Patel.

CALCUTTA SECTION

As Graduates
K. N. Aggarwal; B. R. Chadda.
Transfer
From Student to Graduate
S. S. Marwaha.

CANADA SECTION

As Graduate
R. H. L. Ackerman.
As Students
R. L. Bond; D. S. Binge.

CARDIFF SECTION

As Graduates
A. J. Wall; R. J. Davies.
As Students
M. E. Condron; J. J. Roberts; A. Williams; F. L. Brindley; T. H. Pugh; R. Jones; B. W. Jones; G. F. Lewis.
New Affiliated Firm
Jones Engineers (Machine Tools) Ltd.

CORNWALL SECTION

As Students
I. A. Harrison; A. N. Richards.

COVENTRY SECTION

As Associate Members
N. Edmanson; D. E. Skelley; F. Moore.
As Graduates
R. R. Henson; T. E. Savage; M. J. Berry; D. A. Newell; J. L. Sapsford; M. J. Hill; J. A. Blackwell; R. Moreton; N. J. Wilkes; D. R. Lindsey; J. Hargreaves; W. Staniaszek; L. Foster; H. J. Radford; J. A. Chatwin; W. H. Beck; T. Lenton.
As Students
P. H. Champion; J. L. Churchill; C. A. Peters; A. J. Segrave; J. E. Cooper; R. G. Bradley; D. E. J. Allum; J. G. Carpenter.
Transfers
From Graduate to Associate Member
M. P. Marsh.
From Students to Graduates
D. P. Hutchinson; R. J. Daykin; J. Shaw; M. W. Hancock; R. G. Willson.

DERBY SECTION

As Graduates
W. K. Tyler; T. Adcock; W. M. Cooke; R. Brien; B. Sadler; R. T. Hirst; D. Green.
As Student
E. J. Miller.
Transfers
From Students to Graduates
C. V. Smith; A. R. Taylor.

DUNDEE SECTION

As Associate Member
A. J. Fraser.
As Graduates
H. Foote; J. Crabb; G. W. Galloway; I. R. H. Beattie.
As Students
A. D. Kidney; G. Ogilvie; J. S. Bowman; J. Duff.

GLASGOW SECTION

As Associate Members
F. T. Bright; W. J. Williamson; E. R. Christie.
As Graduates
J. S. Martin; J. Barclay; D. S. Brown.
As Students
G. McCann; G. P. T. Anderson; S. Black; D. M. Maitland; J. Crosbie.
Transfers
From Graduates to Associate Members
T. Murray; R. T. B. Birrell; A. A. Finch; G. W. Fraser.
From Students to Graduates
R. I. Archibald; D. C. Wood

GLOUCESTER SECTION

Transfers
From Graduate to Associate Member
L. J. Beard.
From Students to Graduates
B. A. Millington; A. C. Dancy.

HALIFAX & HUDDERSFIELD SECTION

As Associate Member
D. Lockwood.
As Graduates
A. Holt; B. D. Carter.
Transfer
From Student to Graduate
G. F. Stead.

IPSWICH & COLCHESTER SECTION

As Graduates
N. K. Mandal; N. W. Rushton.
Transfer
From Graduate to Associate Member
D. A. Roberts.

LEEDS SECTION

As Member
N. W. Moore.
As Associate Member
J. Mercer.
As Graduates
P. Bullough; M. D. Hicks.
Transfers
From Graduates to Associate Members
C. B. Dale; E. A. Boyes; W. McAlpine; K. L. Horn; R. C. Taylor.
From Student to Graduate
T. Leadbeater.

LEICESTER SECTION

As Graduates
K. R. Newton; J. R. Sareen.
As Students
D. R. Coleman; R. Dalby; M. Oyarzabel.
Transfers
From Associate Member to Member
E. V. Carter.
From Students to Graduates
D. A. Hall; T. N. Bennett; D. York.

LINCOLN SECTION

Transfer
From Student to Graduate
J. Sherman.

LIVERPOOL SECTION

As Graduates
M. J. Chidley; C. J. D. Butler.
As Students
D. J. Reid; D. Beamer; G. A. D. Popper; P. G. Davies; D. K. Morgan; P. Hughes; R. W. Bloor.
Transfers
From Associate Member to Member
F. B. Schofield.
From Graduate to Associate Member
G. D. Kendrick.

LONDON SECTION

As Members
E. C. A. Goodwin; J. B. Race; J. H. Farmer; R. O. H. Wilkinson.

As Associate Members
G. Lawrence; A. I. McCrerie; J. N. Coker; W. K. Jude; C. S. Clack; M. J. Bunn; J. F. Lucas; L. G. R. Meers; J. L. Lee; N. R. Pratley; G. E. Morley; M. V. Hynes; W. A. L. Smith.

As Graduates
J. Fitzpatrick; B. J. Holloway; J. E. Shaw; D. R. Hipkin; J. A. Worthington; B. Banfield; A. T. Afford; R. M. Hassell; D. F. Ransom; P. M. Slaughter; J. Wisden; A. D. Hitch; P. J. Murgatroyd; E. Harris; K. J. Clench; R. J. Tuthill; A. C. Palmer; M. V. Ellis; J. W. Stringer; G. E. Lewis; A. M. Blew; A. E. J. Monk; R. T. J. Self; P. W. Talkinton; W. E. Wilkes; P. J. Pope; E. W. Lindley; W. W. Webb; B. A. Smith; P. J. Wildhaber.

As Students
B. B. Broughton; D. E. Walsby; D. V. Shaw; B. A. Golding; G. C. Shadbolt; J. A. Fulks; J. P. Harris; P. H. S. Edwards; G. T. Flint; J. D. Townsend; A. J. Murrell; M. H. Blake; T. I. V. Blayney-Simpson; L. J. Fisher; R. V. Perry; G. A. Quiney; A. J. Coleman; D J. Bindley.

Transfers

From Associate Members to Members
G. Walters; D. E. Austin; J. H. Spurr; S. Slingsby; P. White.

From Graduates to Associate Members
G. E. Tout; A. K. Gill; D. L. M. Pickard; A. C. Porter; S. F. Cogger; A. J. Grainer; A. D. Prothero; R. A. Hall; K. A. Crago; A. J. Lawrance.

From Students to Graduates
P D Beedie; K. W. Chappell; P. N. Day; P. E. G. Casemore; J. F. W. Walker; L. W. N. Jones; K. E. Younge; R. D. Bald; M. A. Tinley; C. C. Trott; K. E. Reader; B. E. Bayley; A. C. Faluyi.

LUTON SECTION

As Graduates
P. L. Willson; R. F. Howes; P. J. Hill; J. M. Sharman; M. Murden; P. S. Clark; R. B. Price; R. D. Phillips; M. F. Davy; R. A. King; F. O. Piggott; P. A. Ellis; D. Smith; R. J. Perry; R. S. L. Sayer; D. R. Potter; C. S. Geary.

As Students
F. G. Pearson; J. B. Piggott; G. J. Hill; R. E. Mynott; P. J. Comben; F. Plumb.

Transfers

From Graduates to Associate Members
W. M. Stern; C. S. Morgan.

From Students to Graduates
J. A. Laurie; K. L. Reynolds; N. A. Dilley; G. D. Currie.

MANCHESTER SECTION

As Associate Members
B. F. Crank; D. I. MacDonell; A. Shaw; B. V. Abhyankar.

As Graduates
G Willis, R. O. Lancaster; B. J. Newton; V. A. Cowen; J. R. Noble; H. Owens; J. McCormick; D. S. Ward.

As Students
G. F. Hall; A. Binnie; R. E. Percival; R. J. Aird; D. Picken; H. W. Ratcliffe; C. A. Jones.

Transfers

From Graduates to Associate Members
D. Brownlie; G. R. Connor; I. E. Taylor.

MELBOURNE SECTION

As Member
G. C. Lovitt.

As Graduates
R. I. Johnston; J. N. Sutton.

Transfers

From Associate Members to Members
J. Carter; V. G. Burley; E. F. Faggetter.

From Graduate to Associate Member
D. C. Marley.

NEWCASTLE UPON TYNE SECTION

As Graduates
A. K. Mitra; T. Worswick.

As Student
G. Blue.

Transfers

From Graduate to Associate Member
G. Ellis.

From Student to Graduate
G. Watson.

NORWICH SECTION

As Student
D. R. Newnes.

Transfer

From Student to Graduate
D. St. A. Hunt.

NOTTINGHAM SECTION

As Graduate
P. E. Guy.

As Student
M. G. Cross.

Transfers

From Associate Member to Member
R. F. H. Bush.

From Student to Graduate
J. C. Covell.

OXFORD SECTION

As Graduates
P. J. T. Gorle; H. E. Barber; A. L. French.

As Students
I. L. Slade; R. C. Baker.

Transfer

From Graduate to Associate Member
D. J. R. Merritt.

PETERBOROUGH SECTION

As Graduate
S. S. Mathur.

As Students
M. Brasier-Creagh; J. M. Payne; E. A. Warman.

PRESTON SECTION

As Graduates
A. Kathpalia; P. D. Price; T. K. Henry; J. W. Bell; J. Desai; S. Lynch; A. Bond; J. P. Townsend; J. Marsden.

As Student
D. Scholes.

Transfers

From Graduate to Associate Member
C. H. Scaife.

From Student to Graduate
R. J. Maxwell.

READING SECTION

As Associate Member
W. E. Woodley.

Transfer

From Student to Graduate
G. A. Mills.

ROCHESTER SECTION

As Graduate
A. Goldsmith.

As Students
A. Leggett; J. W. Goodhand; A. J. Clark; J. Swarup.

Transfers

From Graduate to Associate Member
R. C. Stubbs.

From Students to Graduates
D. Neilson; D. R. Gaskin.

SHEFFIELD SECTION

As Students
P. J Wilson; P. Brown; R. Batty.

Transfers

From Associate Members to Members
H. Steel; M. F. Stuart-King.

From Student to Graduate
K. M. Walker.

SHREWSBURY SECTION

As Associate Member
C. N. Lister.

As Graduate
J. R. Willocks

As Student
D. W. G. Uffindell.

Transfer

From Graduate to Associate Member
D. A. Bloom.

SOUTHAMPTON SECTION

As Member
B. W. Boyd.

As Associate Member
J. A. Fielden.

As Graduate
N. G. Badley.

As Students
B. E. Worrall; R. E. Poole.

Transfers

From Students to Graduates
D. Cookson; E. W. Smith; A. J. Morris.

SOUTH AFRICA SECTION

As Students
L. J. J. Muller; B. J. Youngworth.

SOUTH ESSEX SECTION

As Associate Members
V H. Mould; D. E. Brittaine.

As Graduates
C. J. Clark; D. J. Buckley; I. D. Tampen; P. C. Huff; J. W. Charman; R. G. Rowe.

As Students
A. H. Mallard; D. G. Melven.

Transfers

From Graduate to Associate Member
H. Johnson.

From Students to Graduates
J H. Heath; P. S. H. Irvine.

STOKE-ON-TRENT SECTION

As Graduates
C. Tweats; D. E. Rogers.

As Student
R. L. Franklin.

Transfer

From Graduate to Associate Member
A. F. Meadows.

SWANSEA SECTION

As Student
E. G. Bridges.

Transfer

From Graduate to Associate Member
D. F. Ormrod.

SYDNEY SECTION

As Associate Members
N. L. Hannon; G. Lorenz.

Transfer

From Student to Graduate
M. G. Stevenson.

TEES-SIDE SECTION

As Graduates
N. M. Holmes; J. E. Adlington.

As Students
D. J. Davies; J. Wharton.

Transfers

From Graduate to Associate Member
G. J. Fletcher.

From Student to Graduate
A. D. Best.

WESTERN SECTION

As Graduates
I. G. Dauncey; J. Jones.

As Students
A. R. Howarth-Woods; E. R. H. Damagnez; J. E. Halsey; D. J. Haxell.

Transfers

From Students to Graduates
R. Hiscox; M. C. Staley; M. J. Bolwell; J. H. Salt.

WOLVERHAMPTON SECTION

As Associate Member
C. Hayward.

As Graduates
G. Pearson; R. T. Joesbury; D. G. Stern; L. Arrowsmith; E. V. G. Albrecht; J. Higgs; T. F. Tranter; D. Lardge; C. J. Smith; M D. W. Coggins; R. W. Trubshaw.

As Students
P. J. Forrest; R. C. Ellis; R. G. Holding; B. J. Prew; J. Carter; M. S. Akhtar; L. Kureishi.

Transfers

From Graduates to Associate Members
W. T. Massey; J. A. Gough; V. J. Reeve; F. J. J. Haddock; C. J. Micklewright.

From Students to Graduates
H. N. Summerfield; G. W. Holden; K. Knott.

WORCESTER SECTION

As Graduates
H. B. Cartwright; B. Sutor.

As Student
E. J. Wallis.

Transfers

From Graduate to Associate Member
R. J. Mutton.

From Student to Graduate
B. K. Reeve.

NO SECTION

As Member
H. J. L. Dolan.

As Associate Member
F. W. Reed.

Transfers

From Graduate to Associate Member
G. A. Chaudhry.

From Student to Graduate
A. F. Knappert.

REGIONAL MEETINGS

The speaker at this year's South Eastern Regional Meeting will be **Mr. Edwin Fletcher,** Secretary of the Production Department of the T.U.C., who is to give an address on "Industrial Relations and The Production Engineer".

The meeting is to be held on Thursday evening, 23rd April, 1959, at the Royal Commonwealth Society, London.

In the North-West, the 1959 Regional Paper is to be given by **Mr. Allan Ormerod,** A.M.I.Prod.E., Production Director of Ashton Bros. & Co. Ltd., on 27th April, at the Manchester College of Science & Technology. Mr. Ormerod is to speak on productivity in the cotton textile industry.

SEVENTH CONFERENCE ON AIRCRAFT PRODUCTION

Members are reminded that the closing date for the receipt of applications to attend the Seventh Conference on Problems of Aircraft Production is *Monday, 30th March,* 1959.

An application form, together with details of the programme, will be found in the Supplement to this Journal.

CONFERENCE SPEAKERS

Mr. Peter Masefield, Managing Director, Bristol Aircraft, Ltd. (Session II)

Lord Douglas of Kirtleside, Chairman, British European Airways (The Lord Sempill Paper)

NEW PRESIDENT OF THE AUSTRALIAN COUNCIL

Mr. James M. Steer, M.I.Prod.E., a Director of McPherson's Ltd. of Australia, who was recently elected President of the Australian Council, has had a long association with the Institution during which he has made an outstanding contribution to its progress and expansion in Australia.

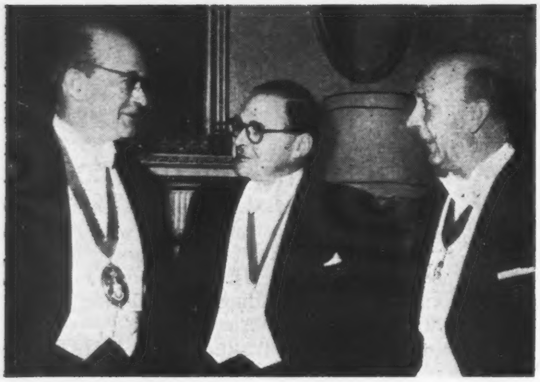
Mr. Steer joined the Institution in 1933, as a member of the Birmingham Graduate Section, and was subsequently Hon. Secretary of the Senior Section for two years. In 1936 he was transferred to Australia by his company, Associated British Machine Tool Manufacturers, Ltd., and assisted in the formation of the first Section of the Institution in Australia, in Sydney. He read a Paper at the inaugural meeting in March, 1938, and was elected Secretary of the Sydney Section, retaining that office until 1948.

When the Australian Sub-Council (as it was then known) was formed in 1944, Mr. Steer filled the office of Secretary for a year until his transfer to another State, South Australia, where he served for three years on the Committee of the Adelaide Section. In 1954, he moved to the State of Victoria and was elected to the Committee of the Melbourne Section, taking office as Chairman of the Section from 1956 to 1958.

He was elected Chairman of the Australian Council in November, 1957 and completed his term of office in October, 1958.

In view of his long, continuous and devoted services to the Australian Council and three Sections, his fellow-members unanimously agreed that he be elected to the highest office — that of President of the Australian Council and of the Institution in Australia. Under his leadership the Institution can look forward to increased activities and enhanced prestige, building on the foundation set by his predecessors.

Mr. S. P. Woodley, General Manager, Vickers-Armstrongs Aircraft, Ltd. (Session III)



The Annual Dinner-Dance of the Newcastle upon Tyne Section was held on 7th January last, when the Section were pleased to welcome among the principal guests the President of the Institution, The Rt. Hon. the Earl of Halsbury, F.R.I.C., F.Inst.P. This photograph shows Lord Halsbury (left) with the Section Chairman, Mr. A. Cameron, (centre) and Dr. W. Reid, Chairman of the Durham Division of The National Coal Board.

LORD AUSTIN PRIZE 1957

Mr. J. F. Percival, Graduate, who was awarded the Lord Austin Prize for 1957, decided to spend the prize money on a visit to the Brussels International Fair. In a letter to the Chairman of the Awards Committee, describing his visit, Mr. Percival writes:

general impressions

"It is only possible in two or three days to gain a general impression of such a vast collection of exhibits and to study a few items in greater detail. I find myself left with three outstanding general impressions and a very high opinion of two of the dozen main Pavilions I was able to visit.

"The first two impressions concern the pleasantness and the ingenuity of the external designs of the buildings, and the beautiful effects produced with flowers, water and light. Being of an architecturally conservative nature, the manner in which the futuristic creations blended with natural surroundings and with the natural adornments of gardens and fountains both surprised and pleased me greatly. Perhaps, as usual, the best of man's efforts please; the second best, which is our more usual lot, leaves much to be desired!

a criticism

"The third and overriding impression is also my one source of serious criticism and this is of the Atomium. This was created to symbolise both the character of the age and of the Exhibition itself; which it did admirably, its size and startling outline giving it a seemingly ubiquitous nature. But what a pity to allow individual industrial companies to exhibit within the sphere, with the consequent self-advertisement and biased presentation! An impersonal and comprehensive story of the past, present and future developments of nuclear and thermonuclear science as the servant of mankind would, I feel, have been a far more fitting story for this prime exhibit to tell.

"The two Pavilions which gave me the greatest pleasure were those of the United Kingdom and the Belgian Congo. Though that of the U.S.S.R. was impressive for the size and power of its exhibits, it was quite cold and unhuman; similarly, that of the U.S.A. with its accent on 'modern living' did not seem to mirror the lives of human beings. But the United Kingdom Pavilion, with the diversity of thought which it expressed, appeared to capture and portray the life of a people more happily than of the other great Powers. In this respect the most natural and expressive Pavilion I saw was that of the Belgian Congo, which was symbolised by the simple statue of a native girl which stood alone in the centre of the large foyer. This figure appeared to welcome one with the words: 'I may seem queer by your standards, and a little misshapen, but I am the centre and purpose of this whole pavilion'.

"The sincere and earnest story told in this building was a startling and welcome contrast to the glittering metal and slightly synthetic nature of so many."

MEMBERS TRAVELLING OUTSIDE THE U.K.

Members who are visiting Australia, New Zealand India, South Africa or Canada are reminded that the Institution has local Sections in these countries, where they will be made very welcome by the Institution's Honorary Officers and members there.

Papers on subjects of interest to production engineers and managers are always welcomed, and any members who are visiting one of the Sections outside the U.K., and who would like letters of introduction, should inform the Secretary of the Institution at 10 Chesterfield Street, Mayfair, London, W.1.

news of members

Honours

The Institution warmly congratulates the following members who have been honoured by Her Majesty The Queen:

Knight Bachelor

Mr. E. J. Pode, Member, Managing Director, The Steel Company of Wales, Ltd. Mr. Pode was President of the South Wales Section of the Institution in 1946/47.

O.B.E.

Mr. T. Bancroft, Member, of Blackburn & General Aircraft, Ltd.; Mr. A. E. Morrison, Affiliated Representative, Managing Director of Moore & Wright (Sheffield) Ltd.

The Institution is also pleased to record that **Mr. B. A. Williams,** C.B.E., Member, has been appointed a Commander of the Order of the Crown by H.M. The King of the Belgians. Mr. Williams is a Past Chairman of the Liverpool Section of the Institution.

Obituary

The Institution records with deep regret the deaths of the following members:

Sir Claude Gibb, Chairman of C. A. Parsons & Co. Ltd., who died suddenly while on a business trip to America. He was Chairman of the North-East Section of the Institution (now Newcastle upon Tyne) in 1946/47.

Mr. Ian Hollins, a director of The British Northrop Company, whose sudden death at the age of 45 greatly shocked his friends and colleagues.

Mr. G. W. Corkindale, an executive of Jackson Industries, Ltd., Luton and responsible for the engineering side of the works. Mr. Corkindale was a member of the Luton Section of the Institution from its inception and had served on the Section Committee for some years.

Mr. D. W. Thomas, Chairman of the Board of Governors of Cornwall Technical College, whose death will prove a great loss to the Cornwall Section. Mr. Thomas took a great interest in Institution affairs, in particular the Compressed Air Conferences which have been organised by the Section.

Changes of Appointment

Mr. D. L. Deshpande, Member, has been elected Chairman of the Mechanical Section of the Institution of Engineers (India) for the next three years.

Mr. K. J. Hume, Member, has been appointed Reader in Production Engineering at Loughborough College of Technology. Mr. Hume is Chairman of the Institution's Membership Committee, and a past Chairman of the Papers Committee.

Mr. R. R. Kenderdine, Member, has been elected a Director of Crompton Parkinson Limited, and becomes a Managing Director. Mr. Kenderdine has been with Crompton Parkinson since 1949 and was Production Engineer at Chelmsford before taking over a Works Directorship.

Mr. L. S. Pitteway, Member, has relinquished his appointment with Taylor, Taylor & Hobson Limited (Rank Precision Industries Ltd.), and has taken up a position as Senior Lecturer in Management Studies at the Nottingham and District Technical College. He is a past Chairman of the Leicester Section of the Institution.

Mr. Stanley F. Steward, C.B.E., Member, has been appointed Director-designate of the British Electrical and Allied Manufacturers Association, and has relinquished his directorships of the Lancashire Dynamo Companies.

Mr. R. E. Wilson, Member, Managing Director, has recently retired from Fescol Limited, London. Mr. Wilson joined the Company in 1928 and during his long service has guided it through a period of considerable expansion. In 1948, Mr. Wilson was awarded one of the Institution's Annual Medal Awards for his Paper on "The Relative Merits of Electro-deposited Nickel and Chromium".

Mr. R. J. Bailey, Associate Member, who until recently was Liaison Design and Production Engineer to Martonair Limited, has been appointed Engineer for the Farnham Factory.

Mr. D. Bridge, Associate Member, has taken up an appointment as Lecturer in the Mechanical Engineering Department at Portsmouth College of Technology.

Mr. R. A. Foley, Associate Member, has been appointed Production Engineer of the Camden Street Group of Messrs. Wilmot Breeden Limited.

Mr. James T. Foster, Associate Member, has terminated his contract with the Burma Oil Co. (1954) Ltd. as Training Officer, Chauk. He has now been appointed as Diesel Engineering Expert to The Regional Diesel Mechanics Marine Training Centre at Dalla Dockyard, Rangoon, under the International Labour Office of the United Nations.

Mr. J. Hartley, Associate Member, has taken up an appointment as Lecturer in Charge, Mechanical and Production Engineering Courses, at Bishop Auckland Technical College, Co. Durham.

Mr. J. N. Hemsley, Associate Member, has recently retired after 20 years' service as London and Southern Counties representative of Messrs. Deloro Stellite Limited.

Mr. W. H. Howes, Associate Member, has been appointed a Director of Newmark (London) Distributors Ltd., a subsidiary Company formed to handle sales and technical services for the Newmark Group.

Mr. W. Mearns, Associate Member, has relinquished his position of Assistant Lecturer, Grade B at Rutherford College of Technology, Newcastle upon Tyne, to take up a position with the Durham Education Authority, as Lecturer in Charge of the combined Mechanical, Electrical, Building and Mining Department, at Consett Technical College.

Mr. E. R. Nicholls, Associate Member, has taken up an appointment with the Ministry of Labour and National Service, London. He was previously stationed at the Government Training Centre, Leicester.

Mr. P. J. Galliford, Graduate, has recently been appointed a Project Engineer to the Metal Box Company Ltd., Production Engineering Division, Swindon.

Mr. E. J. Hathaway, Graduate, has now taken up a position as Chief Instructor of the Metal Box Company's Apprentice Training Centre, Acton.

Mr. J. G. Hyland, Graduate, has relinquished his position at the Safca Aerosol Manufacturing Company Ltd., and has taken up an appointment as Manager of a sister Company of the Safca Aerosol Valve Company Ltd., Bracknell, Berks.

Mr. J. E. Johnson, Graduate, has been appointed General Manager of Tubewrights Ltd., Newport, Mon.

Mr. R. Worrall, Graduate, has recently taken up an appointment as Management Analyst with the Iranian Die Refining Company at Abadan, Iran.

DIARY DATES FOR 1959

March 11th ... ... **The 1958 Viscount Nuffield Paper,** to be presented at the University of Birmingham.

Speaker: **Dr. N. P. Inglis,** Metals Division Research Director, Imperial Chemical Industries Limited.
Subject: **"The Production, Fabrication, Properties and Uses of Some of the Newer Metals".**

April 16th/17th ... **The Seventh Aircraft Production Conference, Southampton.** (See Supplement to this Journal.)

April 29th ... ... **The 1958 George Bray Memorial Lecture,** to be presented in London.

Speaker: **Mr. Mark Bogod,** Director, J. Lyons & Co. Ltd.
Subject: **"The Search for Productivity in a Food Industry."**

October 12th ... ... **The 1959 E. W. Hancock Paper**, to be presented in Bristol.

Speaker: **Mr. R. A. Banks,** Personnel Director, Imperial Chemical Industries Limited.
Subject: **"Human Relations in Industry."**

November 19th ... **The Annual Dinner,** Dorchester Hotel, London, W.1.

Hazleton Memorial Library

ADDITIONS

Association of Light Alloy Refiners and Smelters, London. **"The Properties and Characteristics of Aluminium Casting Alloys."** *London, the Association,* 1958. 105 *pages. Tables.* 4s. 6d.

The first A.L.A.R. data sheet was published in 1945. Since then 20 sheets or sets of sheets have been distributed. This edition contains all the data included in the larger version and, in addition, devotes a number of pages to nine standard alloys. Revision has enabled the presentation to be simplified and much of the earlier duplication of data — unavoidable in separately printed sheets — has been avoided. Contents: Standard aluminium casting alloys — Guide to the selection of aluminium casting alloys — Properties and characteristics of individual alloys — The heat treatment of aluminium alloy castings — Identification of aluminium casting alloys.

Barnes, Ralph M. **"Motion and Time Study Applications."** *New York, Wiley,* 1958. 188 *pages. Diagrams. Charts.*

The material in this volume was prepared for use in college courses, for use by industries conducting training courses and as a manual for all those interested. Most of the studies are correlated with films which may not be available in this country, but this fact does not altogether detract from the usefulness of the book, since the illustrations, diagrams and charts are profuse and clear. The studies include: "Motion study applied to clinical dentistry"; "A study of simultaneous symmetrical hand motions"; "How shape of pin affects bar-positioning time"; "A study of numerical ticket sorting"; "An application of time standards for strip stock punch press work". The book should be a useful adjunct to the basic text books of work study theory.

Boneham, W. **"Fine Boring and Turning."** *London and Brighton, Machinery Publishing Company,* 1958. 67 *pages. Illustrated. Diagrams.* 5s. (Machinery's Yellow Back Series, No. 43.)

Contents: Basic principles — Fine boring machines — Heads and quills — Cutting tools, feeds and speeds, and coolants — Fixture design and fine boring applications.

Bryan, Leslie A. **"Traffic Management in Industry."** *New York, Dryden Press,* 1953. 452 *pages. Diagrams.* £2 4s. 0d.

Contents: The field of traffic management — Functions of a traffic department — The geography of traffic — Organisation and administration of a traffic department — Bills of lading — Other shipping documents — The shipping department — The receiving department — Routing of shipments — The rate department — Freight classification — Tariffs — Expediting freight services — Special freight services and privileges — Interplant transportation — Materials handling and storage — Local transportation — Express, mail and passenger services — Claims — Commission procedures and practice.

Carson, Gordon R. (editor). **"Production Handbook."** 2nd edition. *New York, Ronald Press,* 1958. 29 *sections. Various paging. Illustrated. Diagrams.*

The second edition of Alford and Bangs's *Production Handbook,* which has for long been a basic management reference book for production engineers. The 25 sections contributed by specialists comprise: Plant organisation — Production planning and control — Production control systems and procedures — Materials control and standardisation — Purchasing — Storekeeping — Inspection — Quality control — Statistical methods — Charting and graphic methods — Process charts — Work measurement and time study — Motion and methods study — Work simplification — Wage plans and controls — Electronic computers — Research and development — Operations research — Plant layout and location — Manufacturing processes — Tools — Jigs and fixtures — Machinery and equipment economics — Materials handling — Plant maintenance — Safety and fire prevention.

De Paula, F. Clive. **"Management Accounting in Practice."** An examination of some of the problems that arise. *London, Pitman,* 1959. 158 *pages.* 18s.

Much has been written about the theory of management accounting. This book is an attempt to discover some of the problems that arise when the theories are put into practice. Contents: The development of accounting in industry — Installing standard costing, budgetary control and variance accounting — Budgeting outputs for standard costs — Who wants what costs? — How and when costs should be presented — The treatment of variances in end-year stock in trade — The control of service department costs — Fuel and steam costs — The link between shop floor records and management accounts — The financial implications of plant installation and their effect on product costs — Conserving resources of working capital — Mechanised accounting and electronic computers.

Farr, Michael. **"Design in British Industry."** A mid-century survey, with a foreword and postscript by Nikolaus Pevsner. *Cambridge, University Press,* 1955. 332 *pages. Plates.* 65s.

A survey of the work of industrial designers of consumer goods, including domestic appliances, radio and television cabinets, pottery, glass, leather goods, motor-cars and furniture. There are chapters on the place of the craftsman in industry, on design standards, utility schemes, on the education of designers, and the relationship of mass-production to design.

Hunter, Donald. **"Health in Industry."** Diseases and accidents to which workers in industry are liable, and how they may be treated and prevented. *Harmondsworth, Middlesex, Penguin Books,* 1959. 288 *pages. Photographs.* 4s. (Penguin Medical Series.)

The author is senior physician to the London Hospital, and a specialist in industrial medicine. The book is interesting in that it includes information on the nature of the various industrial diseases. The book is not intended to be a *vade mecum* for those concerned with the health and safety of workers in particular industries, but it adequately fulfils its purpose of providing a generalised introduction to the problems of industrial hygiene. Contents: History of industrial medicine — Legislation affecting the worker — Poisoning by metals and their compounds — Poisoning by organic compounds — Dust diseases of the lungs — Other occupational diseases — Glossary of technical terms — Suggestions for further reading and reference.

"Kempe's Engineers Year Book." 64th edition. 2 volumes. *London, Morgan Brothers (Publishers), Ltd.,* 1959. 1,324 *pages,* 1,416 *pages. Diagrams. Tables.* £4 2s. 6d.

The information contained in this reference book covers almost every branch of engineering. Additions have been made to 24 chapters, and the following chapters have been re-written: Flow metering and mechanical testing— Refrigeration — Paints and varnishes.

Metzger, Robert W. **"Elementary Mathematical Programming."** *New York, Wiley; London, Chapman and Hall,* 1958. 246 *pages. Diagrams. Tables.* 48s.

Designed for the reader with a limited background in mathematics who wishes to understand the basic techniques and applications of mathematical programming. Chapter 1 provides general and introductory material about operations research and mathematical programming. Chapters 2, 3 and 4 present the three groups of methods, namely, distribution, simplex and approximation methods, with sample problems which for the most part are sufficiently simple to be solved by inspection. Chapter 5 contains the complete solution and analysis of two typical industrial problems: a manufacturing and a blending problem. Chapter 6 discusses the applicability of high-speed computers for solving problems. Chapters 7, 8 and 9 illustrate the details of various problems solved by mathematical programming: in production planning, stock slitting, materials handling scheduling and job and salary evaluation. There is a fairly extensive graded bibliography. This book is a useful introduction to operational research, particularly for the engineer or manager who wishes to understand "how it works", and who has usually to choose between the non-technical work which in effect tells only what operational research can do for him, and the scientific work, which is comprehensible only to advanced mathematicians.

Pound, J. **"Practical Radio Frequency Heating for the Wood Industry."** *London, Heywood,* 1957. 198 *pages. Illustrated. Diagrams.* 30s.

The author's object is to explain in non-technical language how radio frequency heating works and how it is applied in the wood industry. Contents: Adhesives — General principles of radio frequency heating — Generators — Jigs — Through and transverse heating — Glue line heating — Stray field heating — Miscellaneous applications — Matching — Other heating methods — Economics of radio frequency heating.

Truxall, John G. **"Control Engineers' Handbook."** Servomechanisms, regulators and automatic feedback control systems. *London, New York, McGraw-Hill,* 1958. 19 *sections. Various paging. Diagrams.* £7 3s. 6d.

A handbook for engineers, designers and development engineers on components and techniques for use in the design of feedback control systems. Contents: Tables and mathematics — Basic feedback control system theory — Design technique — Specialised design techniques — Computers in control — Electronic control elements — Magnetic amplifiers — Transistors and miniaturisation — Thyraton amplifiers — Contactors and relays — Electric power supplies — Electro-mechanical actuators — Mechanical components — Clutches and brakes — Hydraulic controls — Pneumatic components — Signal transducers — Regulators.

Vickery, B. C. **"Classifications and Indexing in Science."** *London, Butterworth's Scientific Publications,* 1958. 185 *pages.* 25s.

The storage and "retrieval" of scientific and technical information becomes more difficult as more information becomes available, and as the inter-relationships of the various sciences and technologies become more complex. Machine retrieval systems which may help are still in the experimental stage and must, in any case, be based on a sound classification scheme. A classification scheme performs two functions: it identifies the object searched for, and it indicates its relationship to other objects. This book is a manual on the construction and use of classification schedules for science and technology, and on subject indexing. Its emphasis is on the combinatory or "faceted" type of classification, which, whether or not recognised as such, is familiar to many punched card users. The title of the book precisely indicates its scope: it is a convenient summary of modern thought and practice in the field of classification of scientific information, and touches only incidentally upon the basic logical principles which underlie classification schemes.

Woodward, Joan. **"Management and Technology."** *London, H.M.S.O.,* 1958. 40 *pages. Diagrams.* (Department of Scientific and Industrial Research. Problems of Progress in Industry, No. 3.) 2*s.* 6*d.*

The object of this series of pamphlets is to present briefly the results of research into the social, economic and technical problems of industrial progress. The research described in this pamphlet was an attempt to discover whether the principles of organisation propounded in management theory correlate with business success when put into practice. It was carried out by the Human Relations Research Unit of the South East Essex Technical College, which studied 91% of the firms in South Essex with over 100 employees. "It appeared from the studies that technical methods were the most important factor in determining organisational structure, and in setting the tone of human relationships inside the firms. The widely accepted assumption that there are principles of management valid for all types of production systems seems very doubtful — a conclusion with wide implications for the teaching of the subject . . . the danger lies in the tendency to teach principles of administration as if they were scientific laws, when they are really little more than administrative expedients found to work well in certain circumstances but never tested in any systematic way . . ." This does not mean, says the author, that management theory has no value, but its limitations must be recognised, and its principles subjected to critical analysis. "In the field of management studies many more descriptive accounts like that given here, of the circumstances in which different administrative expedients have proved successful, are required to supplement traditional teaching."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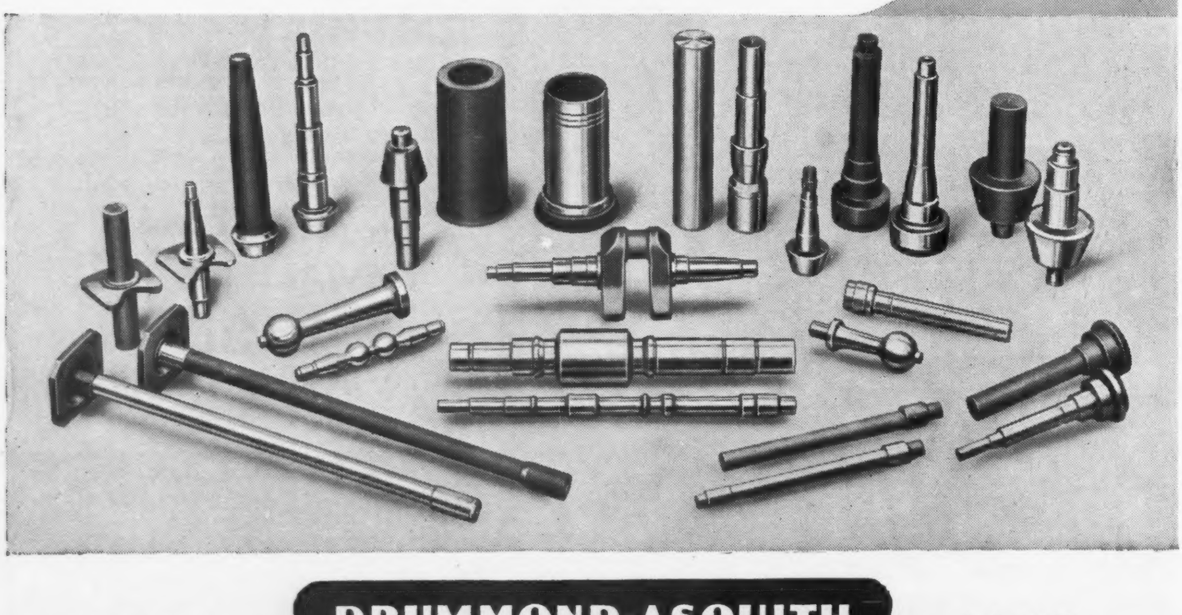

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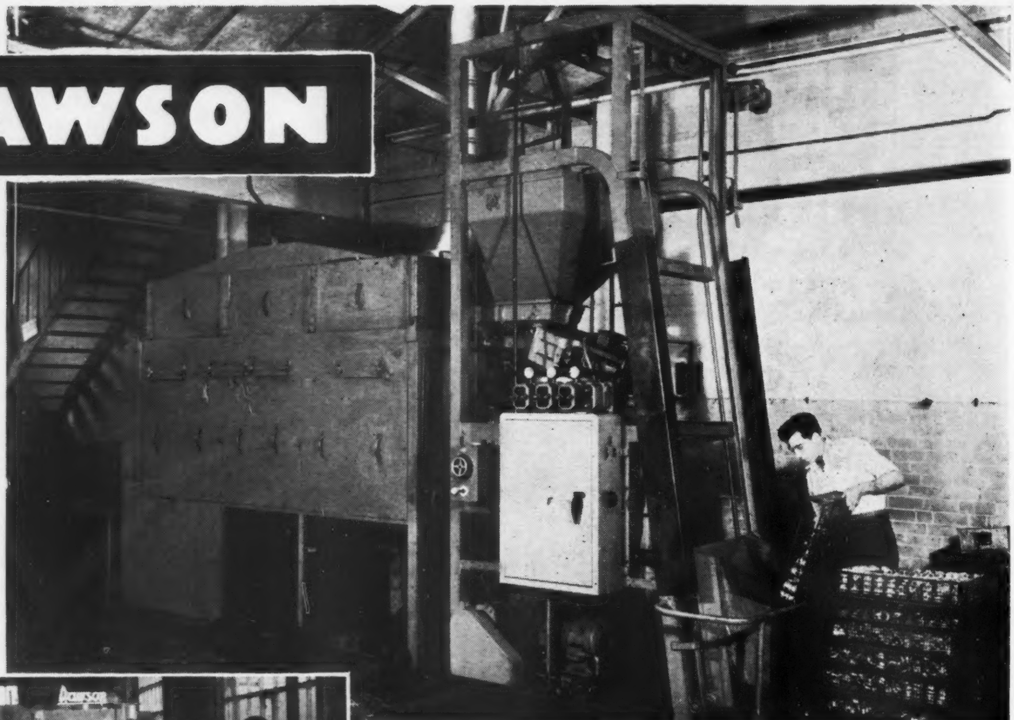

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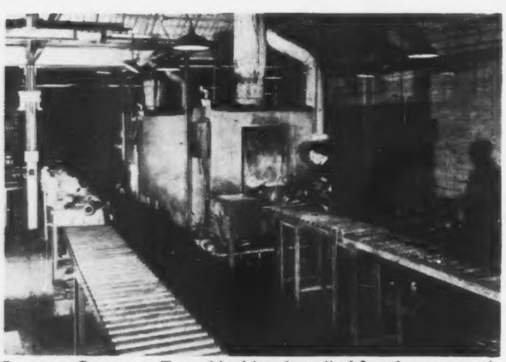

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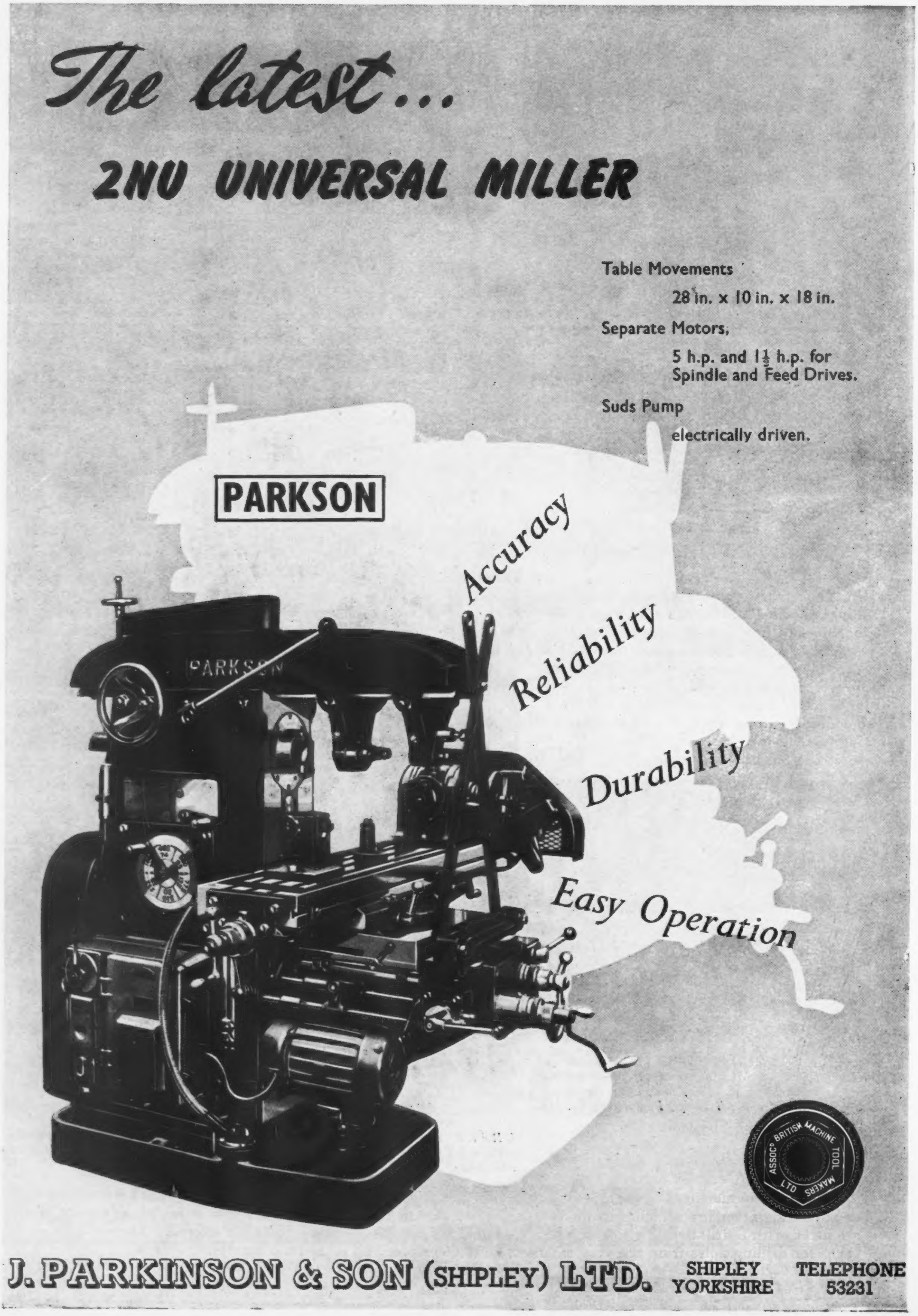
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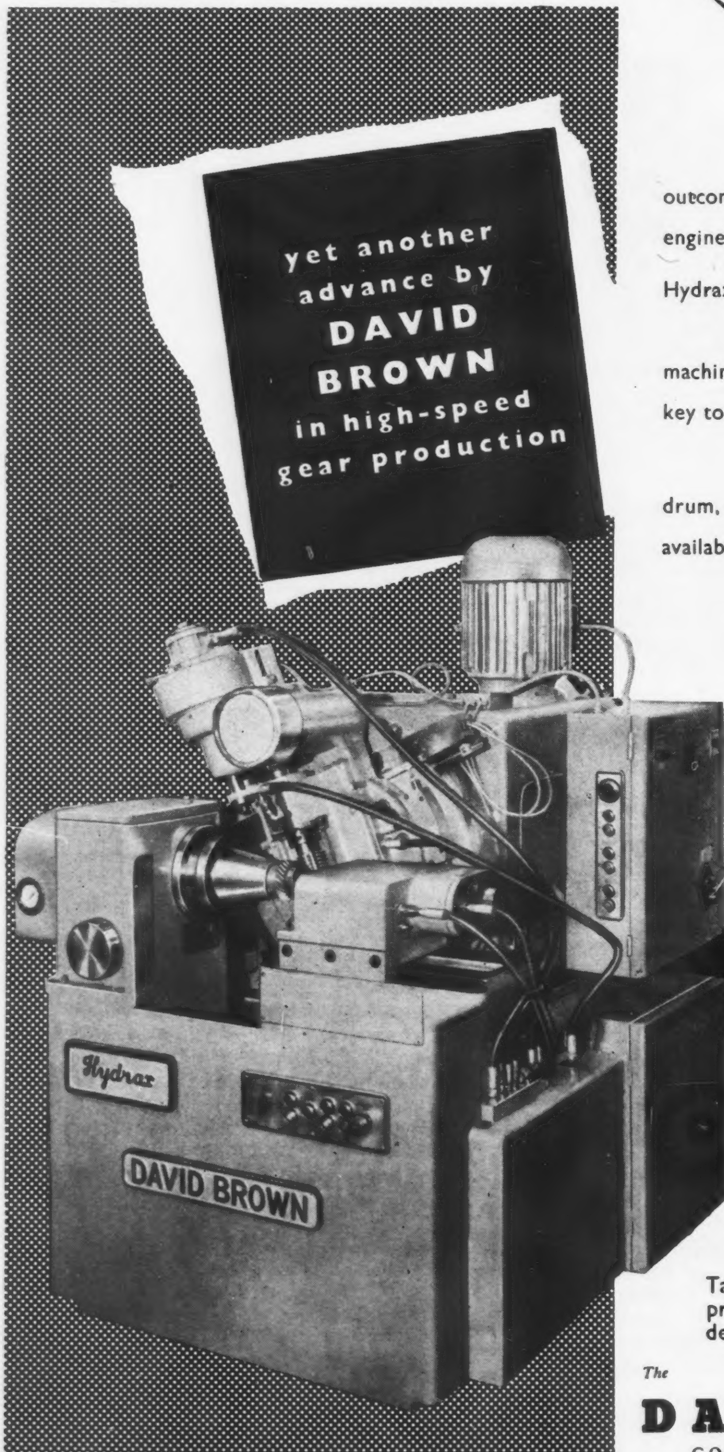

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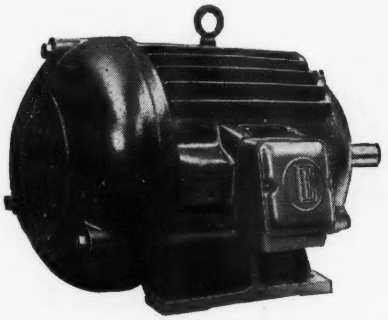

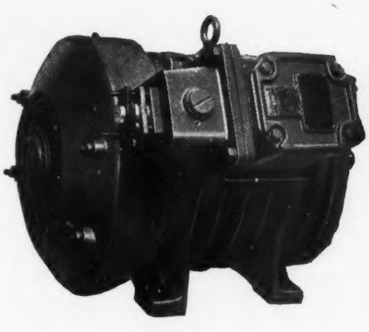

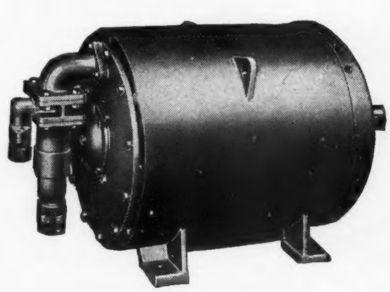

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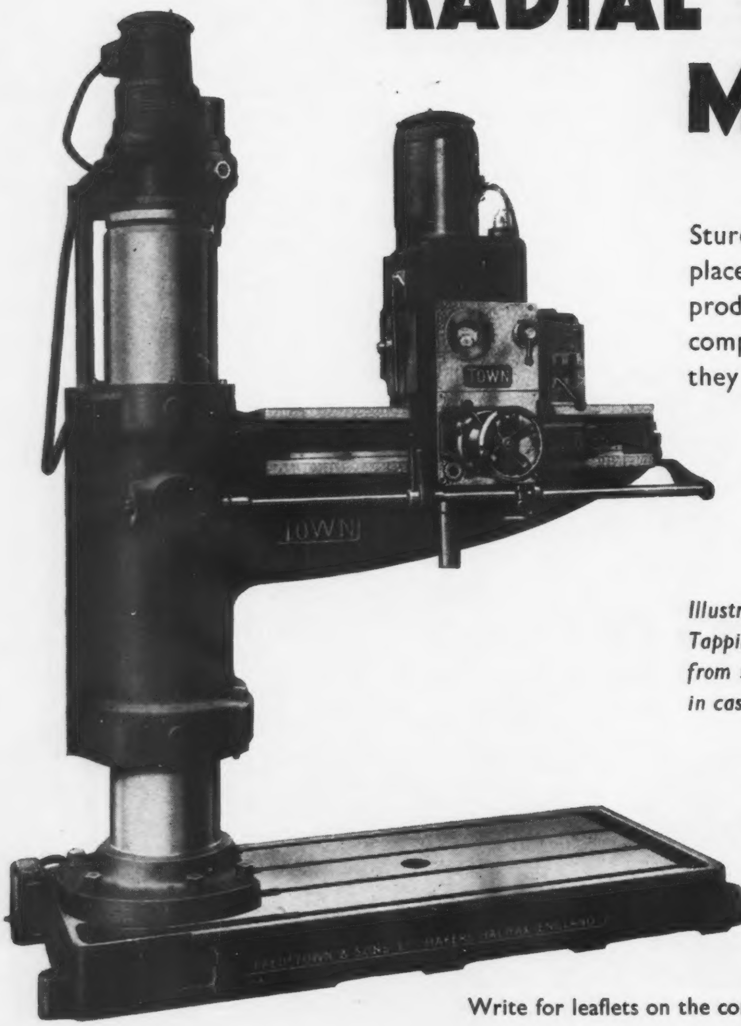
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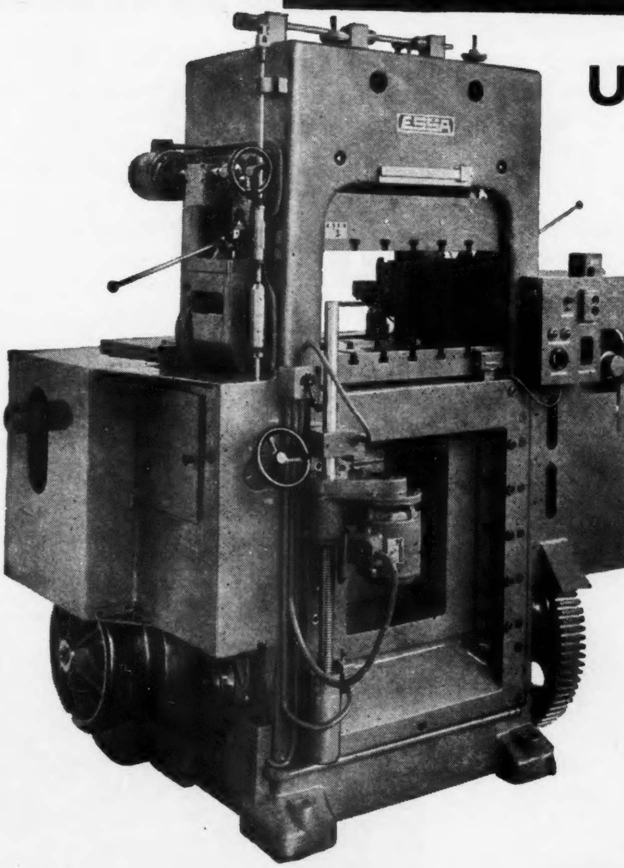

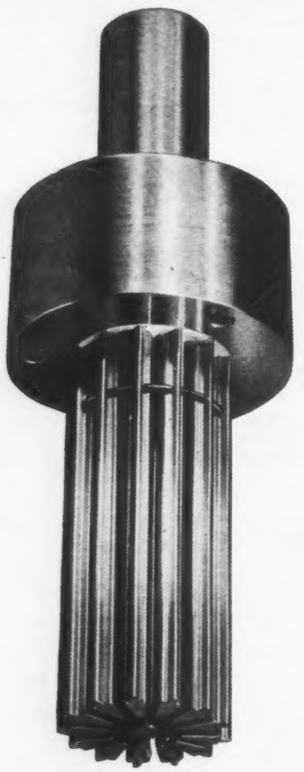

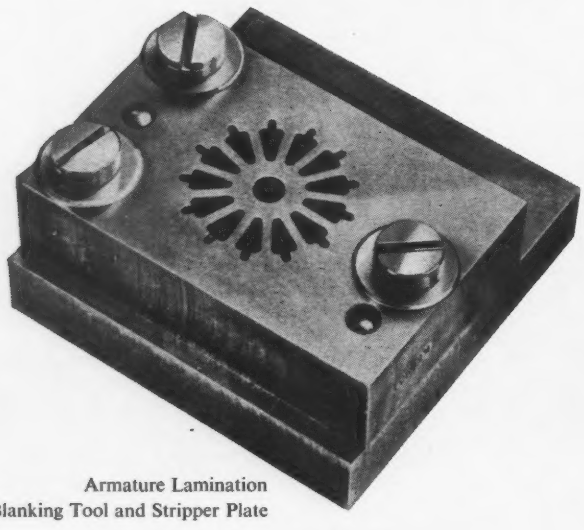

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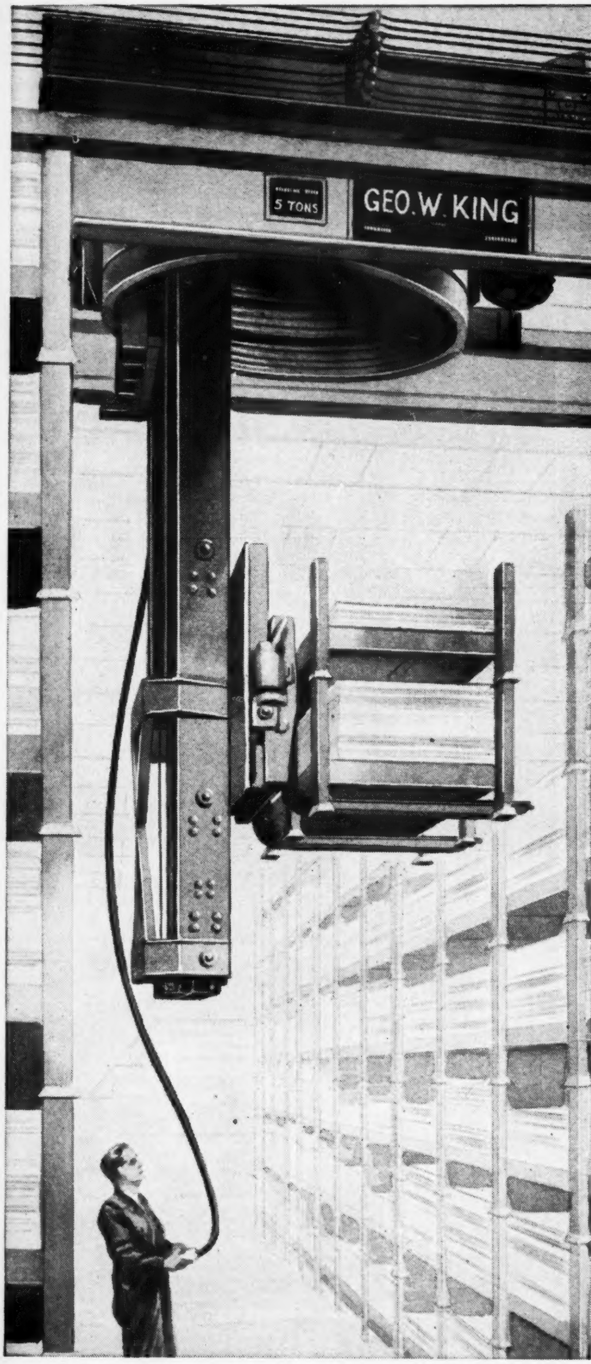

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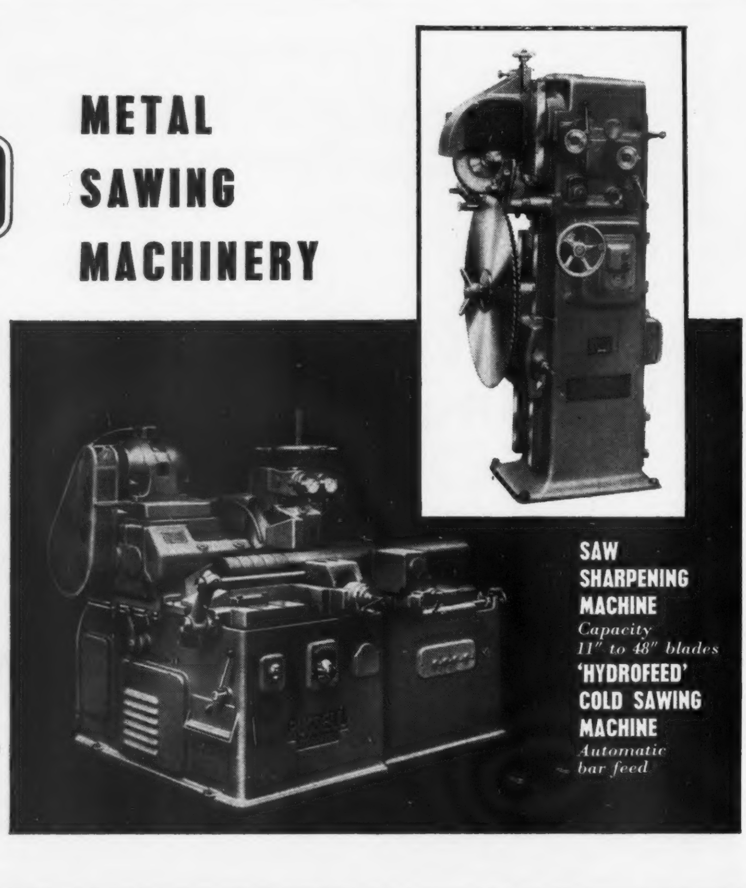

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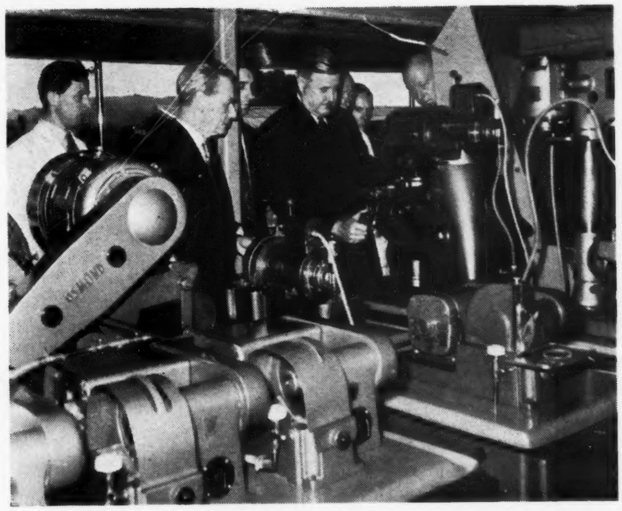

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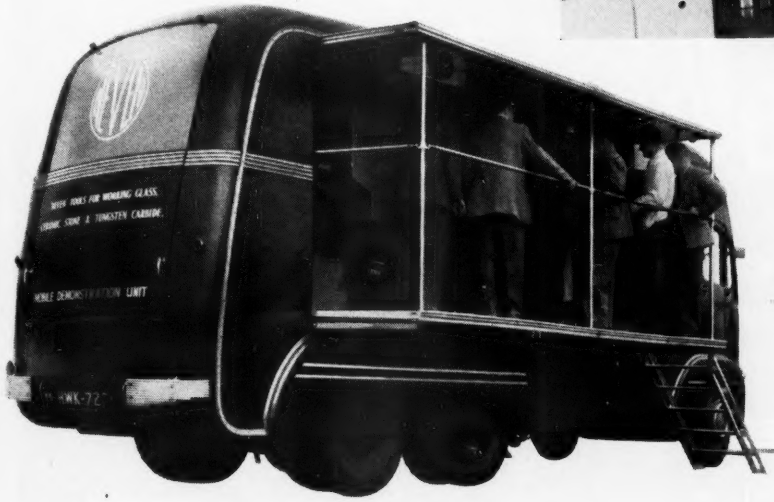

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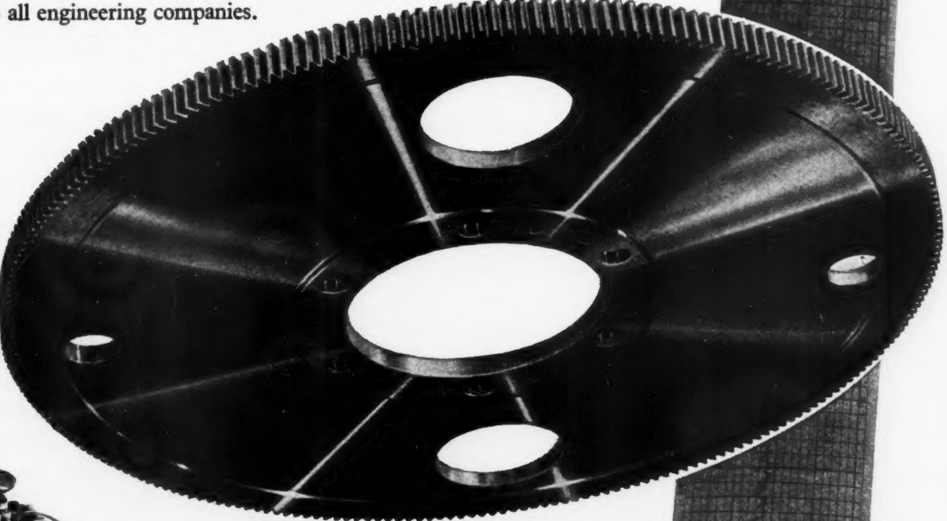

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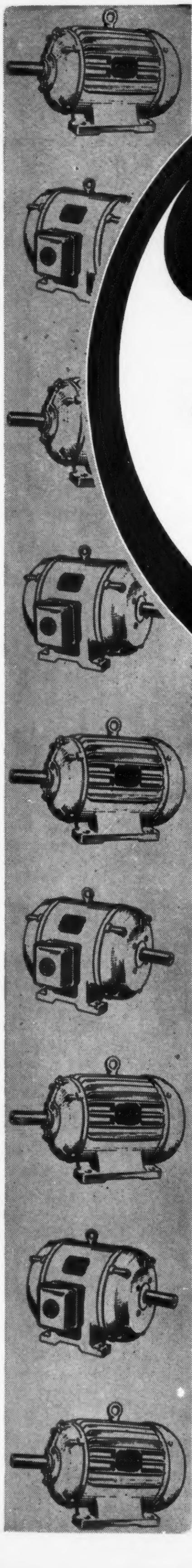

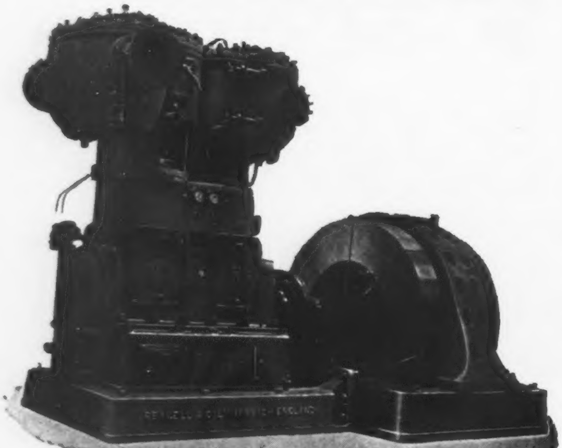

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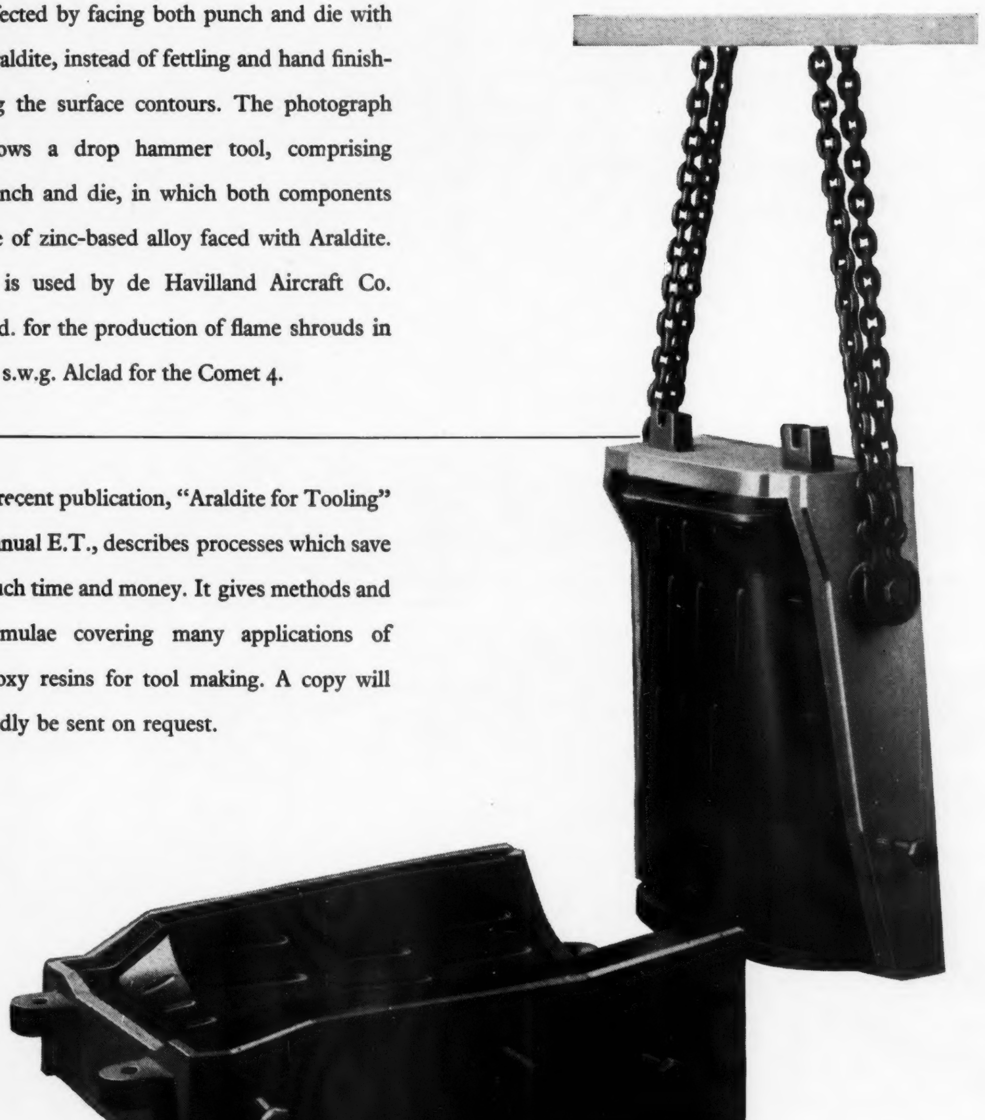

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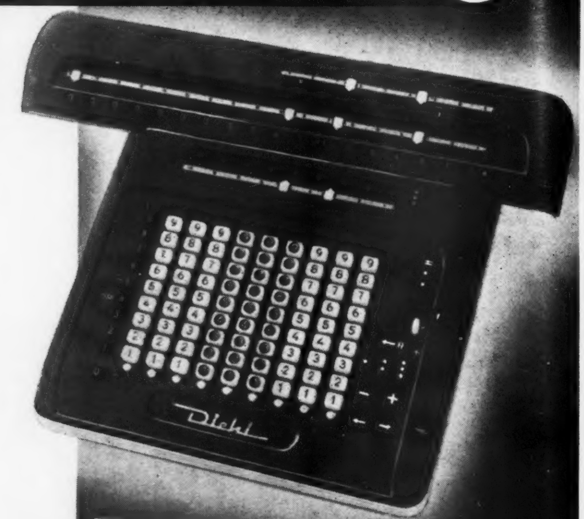

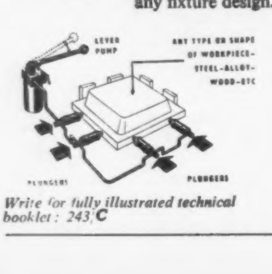
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